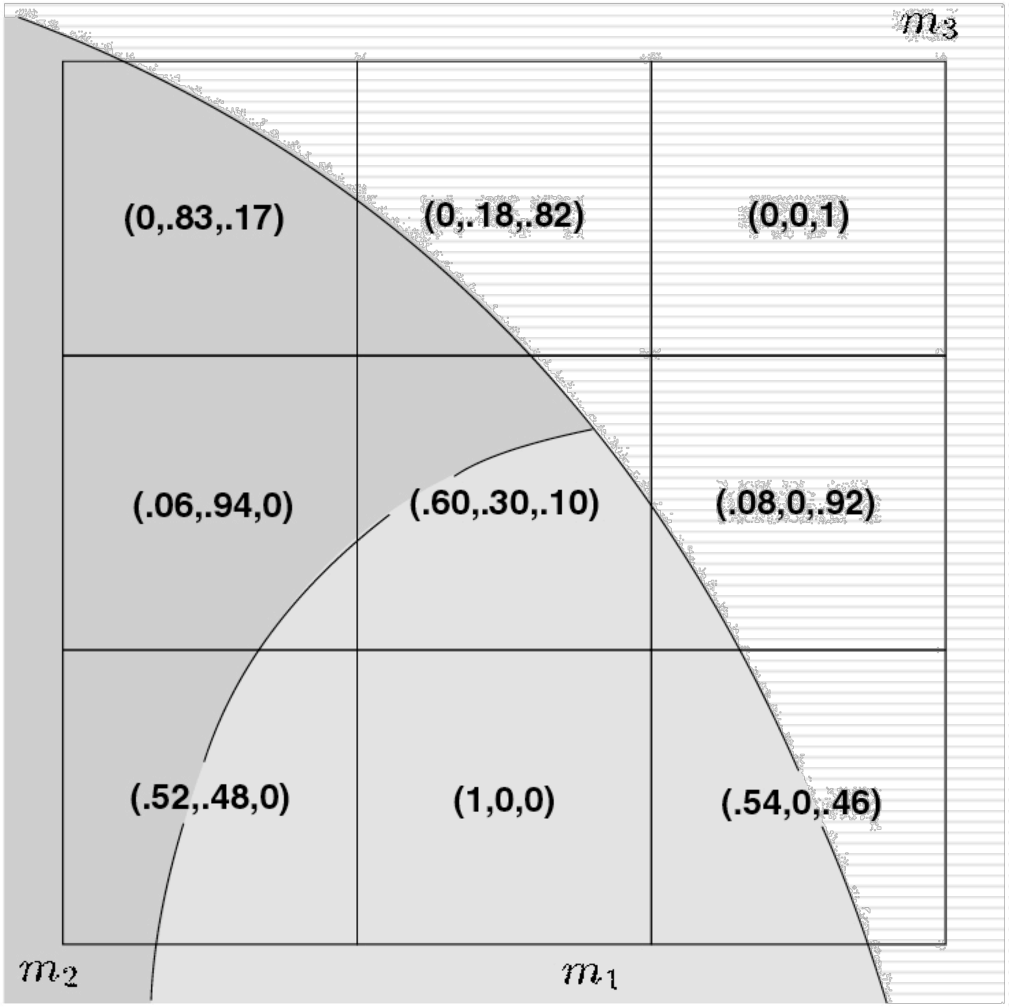
Visualization of Material Interfaces

Kenneth I. Joy
Co-Director, Institute for Data Analysis and Visualization
Professor, Computer Science Department
University of California, Davis

The Problem

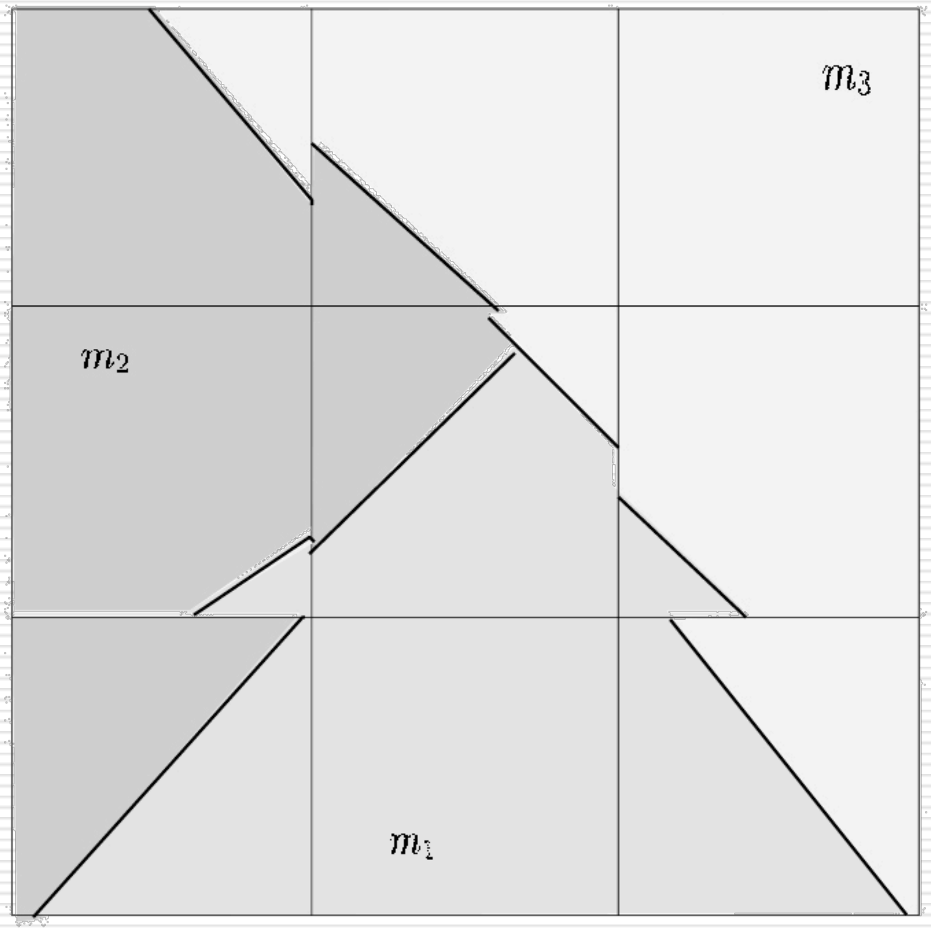
- We want to generate a crack-free piecewise C^0 separating surface approximating the boundary surfaces between various materials, given only that grid cells contain fractional volumetric information for each of the materials.

The Problem



Each cell contains a set of fractions representing the amount of each material that intersects the cell.

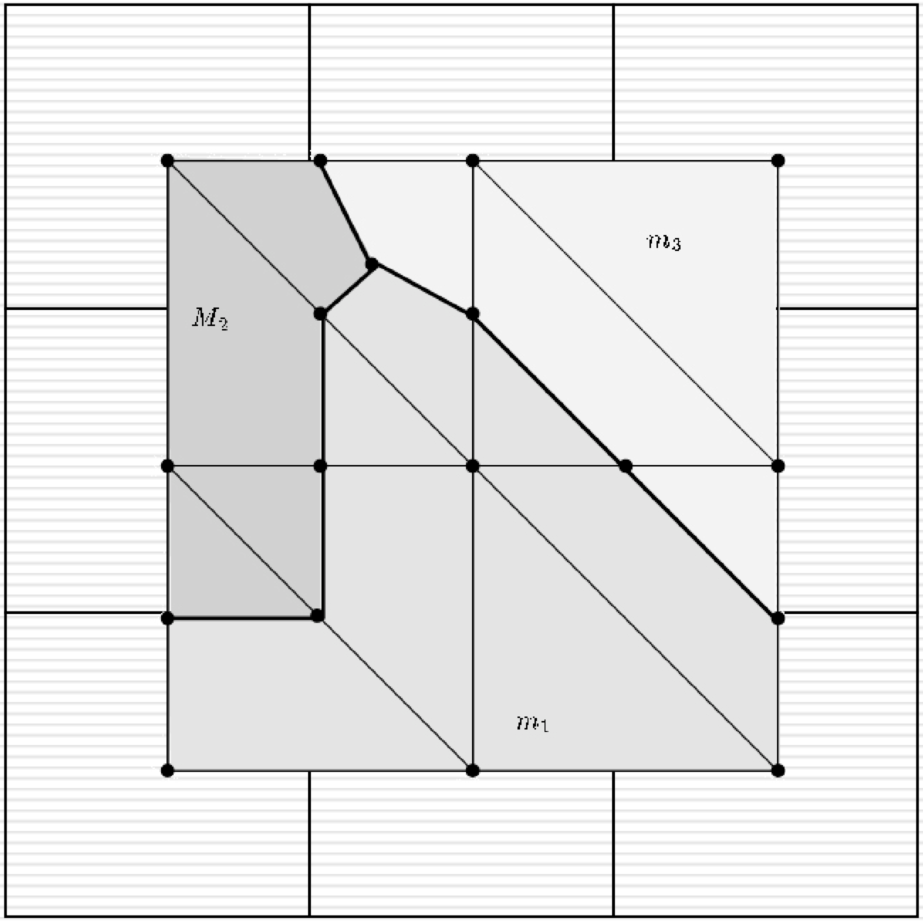
Previous Work



D.L. Youngs, “Time-dependent multi-material flow with large fluid distortion,” *Numerical Methods in Fluid Dynamics.*

Neighbor cells are used to construct the slope of a line segment approximating the interface. The line segment is then adjusted to preserve the volume fractions in a cell.

Previous Work



Nielson and Franke, "Comparing the Separating Surface for Segmented Data," IEEE Visualization 1997

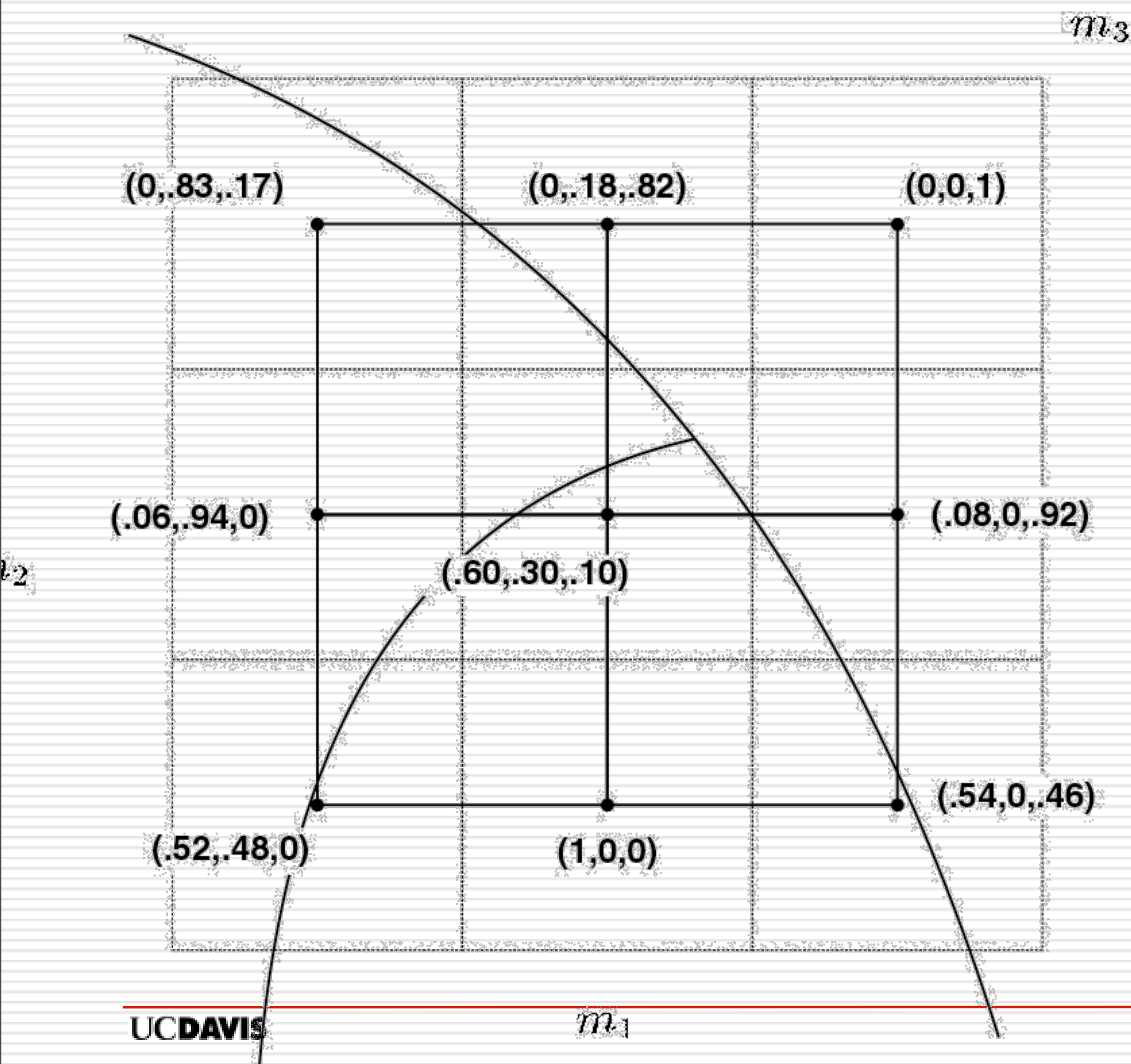
Assumes that each cell belongs only to one material.

Generalizes marching cubes.

Previous Work

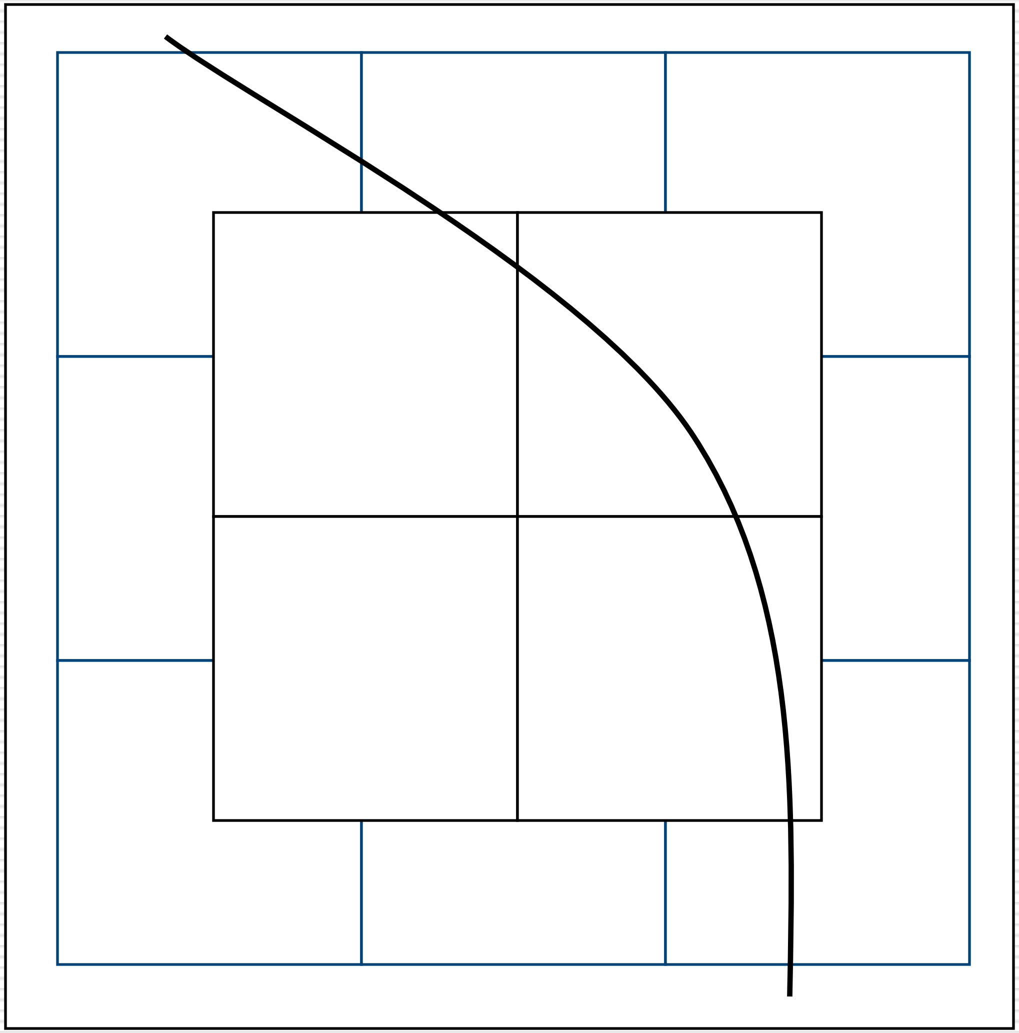
- At LLNL (Now Oak Ridge)
  - Jeremy Meredith has developed methods to develop and implement material boundary reconstruction in VisIt.

Bonnel's Method



Each point on the dual grid has associated a barycentric coordinate (α_1, α_2,…, α_n), where $\alpha_1+\alpha_2+\ldots+\alpha_n=1$.

The Two-Material Case



Each point on the dual grid has associated a barycentric coordinate (α_1, α_2),where α_1 +α_2=1.

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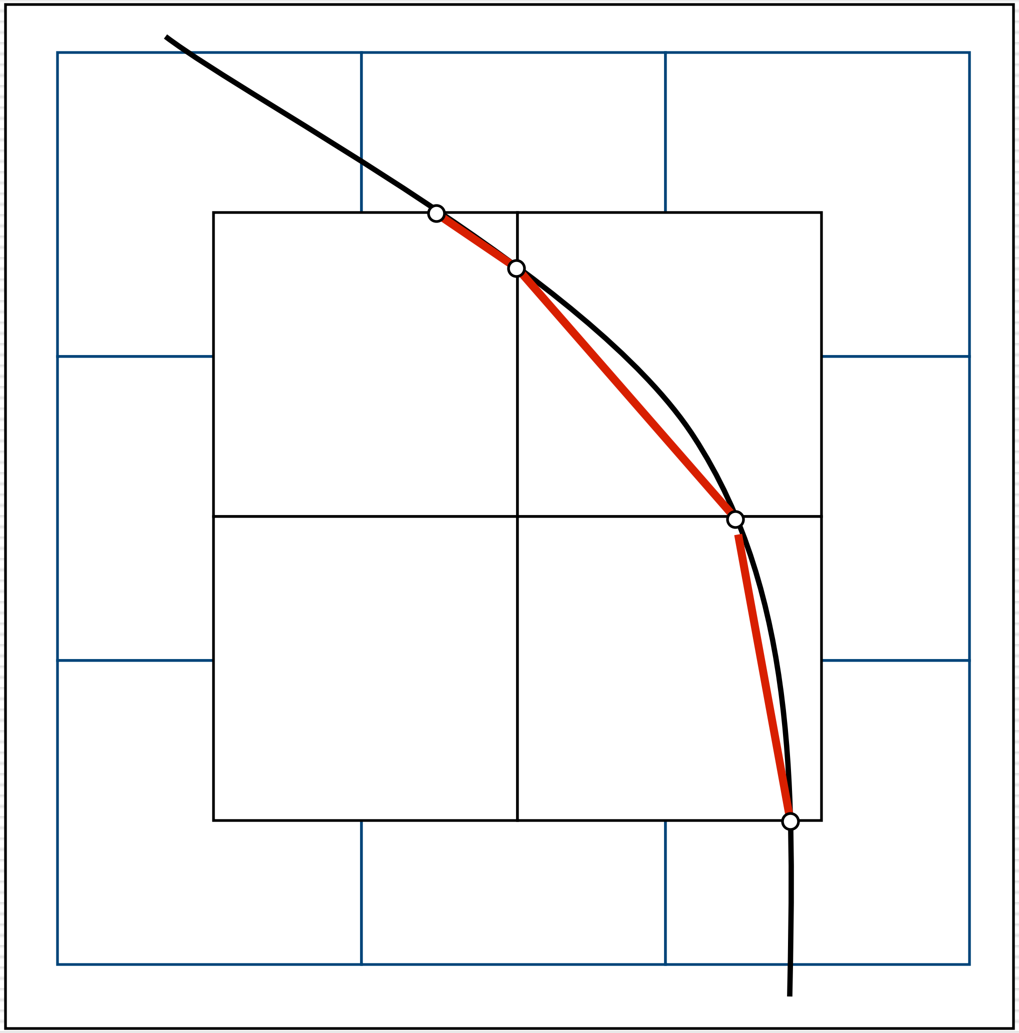

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We want to generate the approximation represented by the red line.

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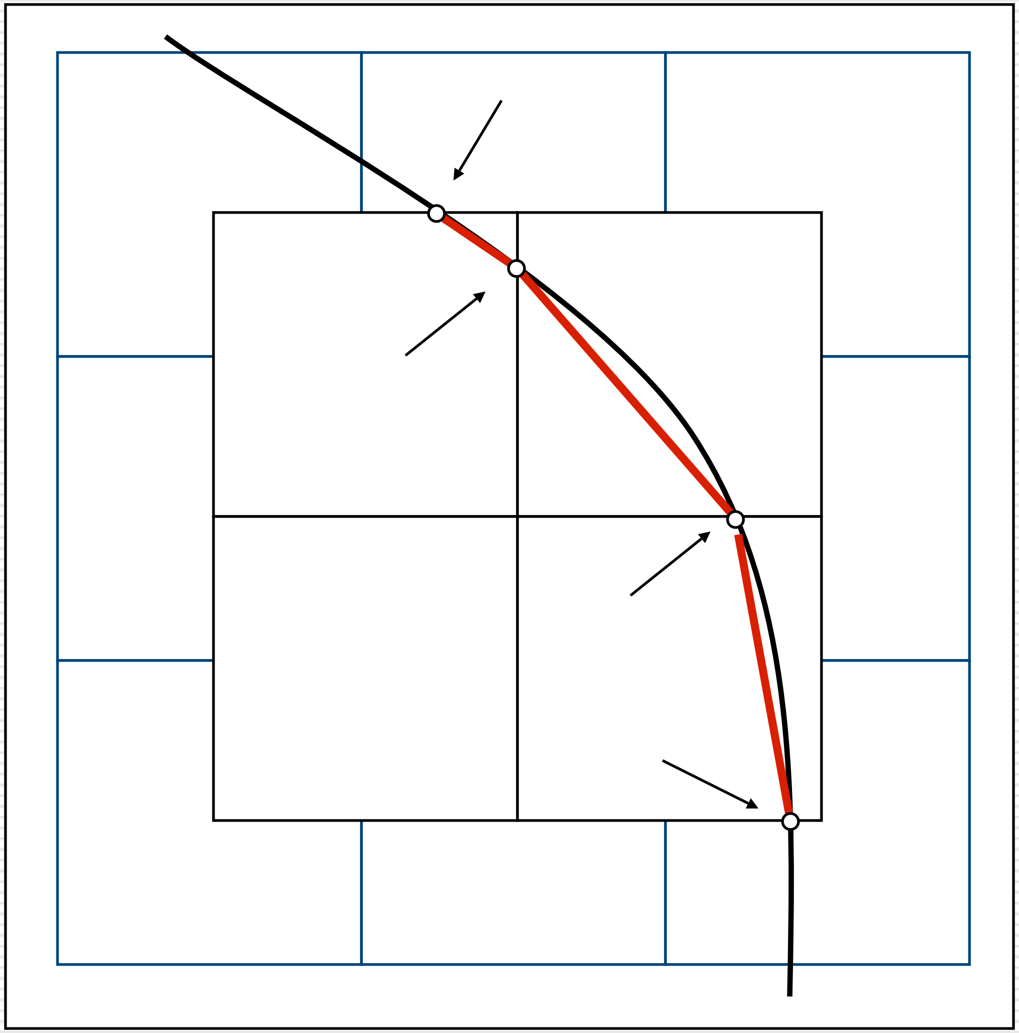

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We must find these intersection points.

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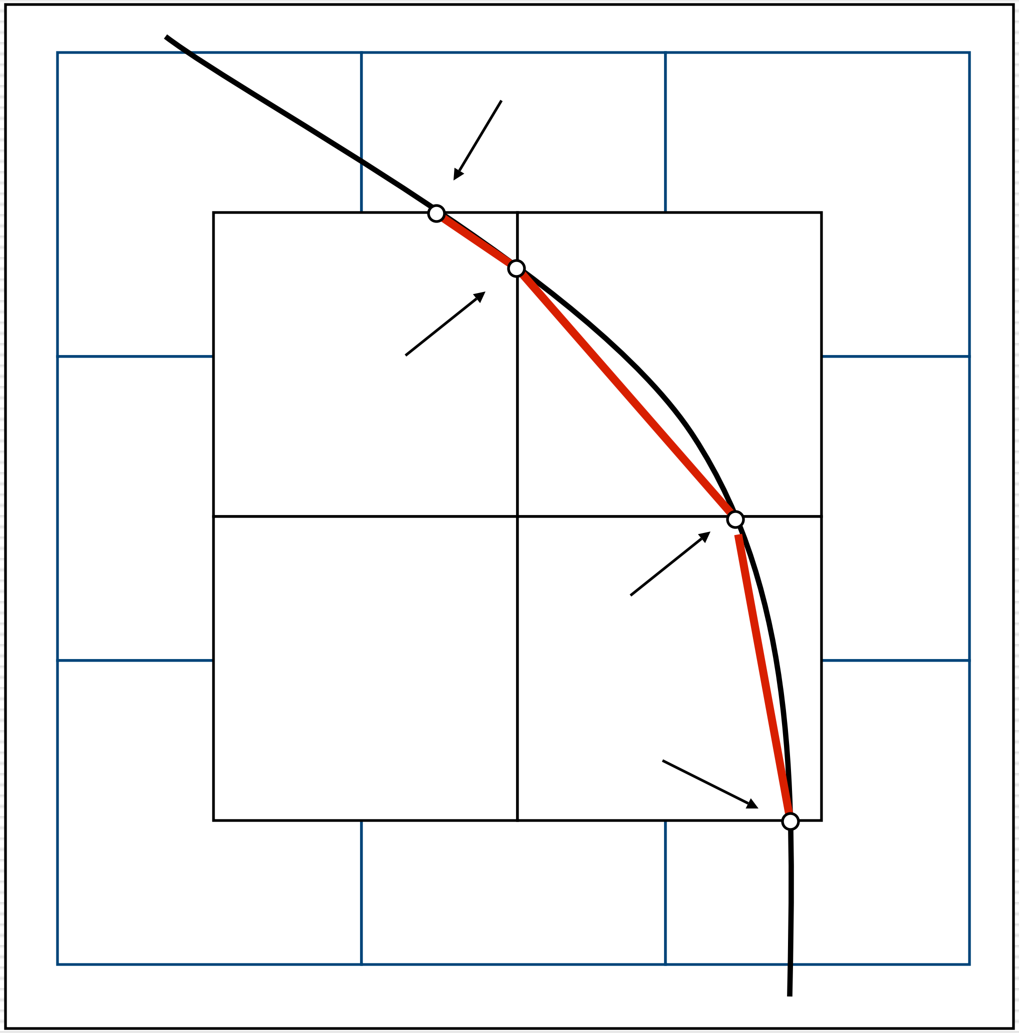


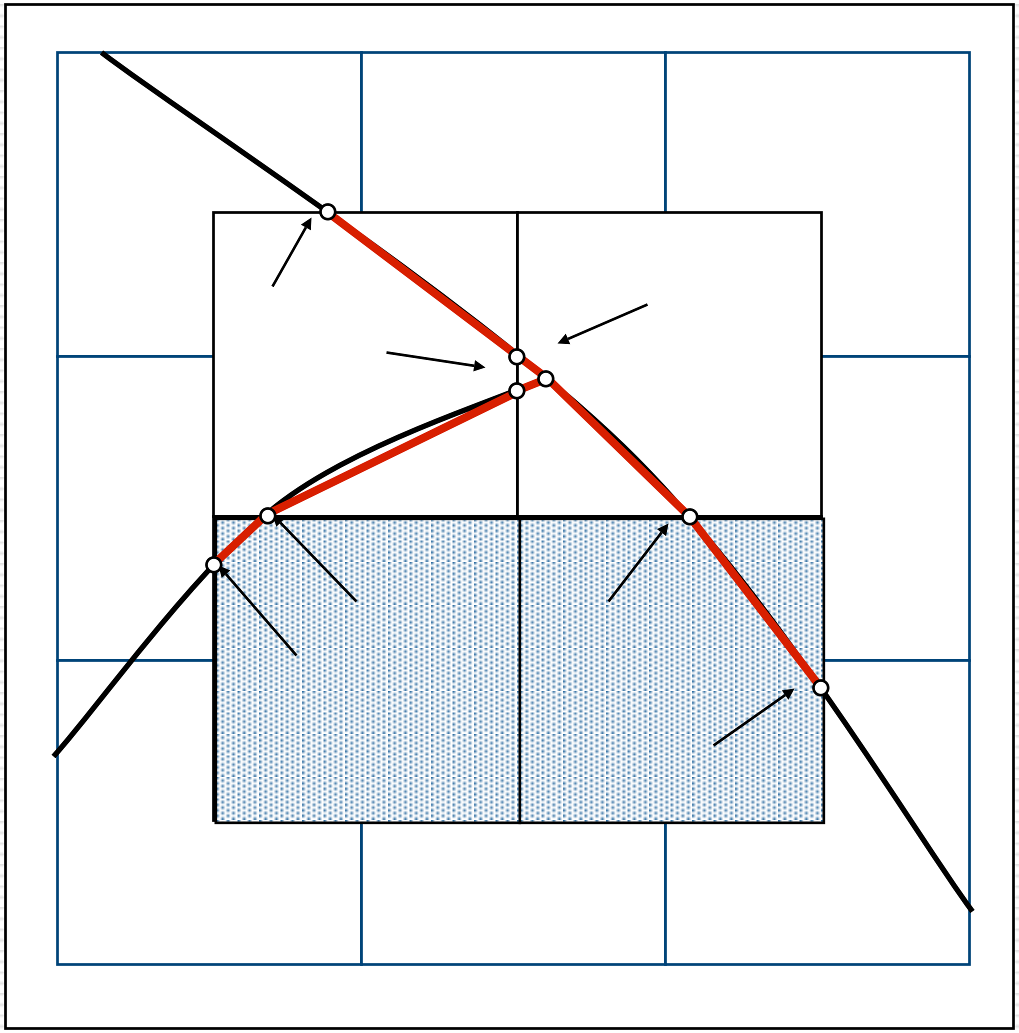
Each point on the dual grid has associated a barycentric coordinate (α_1, α_2),where $\alpha_1 + \alpha_2 = 1$.

We want to generate the approximation represented by the red line.

We must find these intersection points.

To find the intersections, we use linear interpolation in barycentric space.

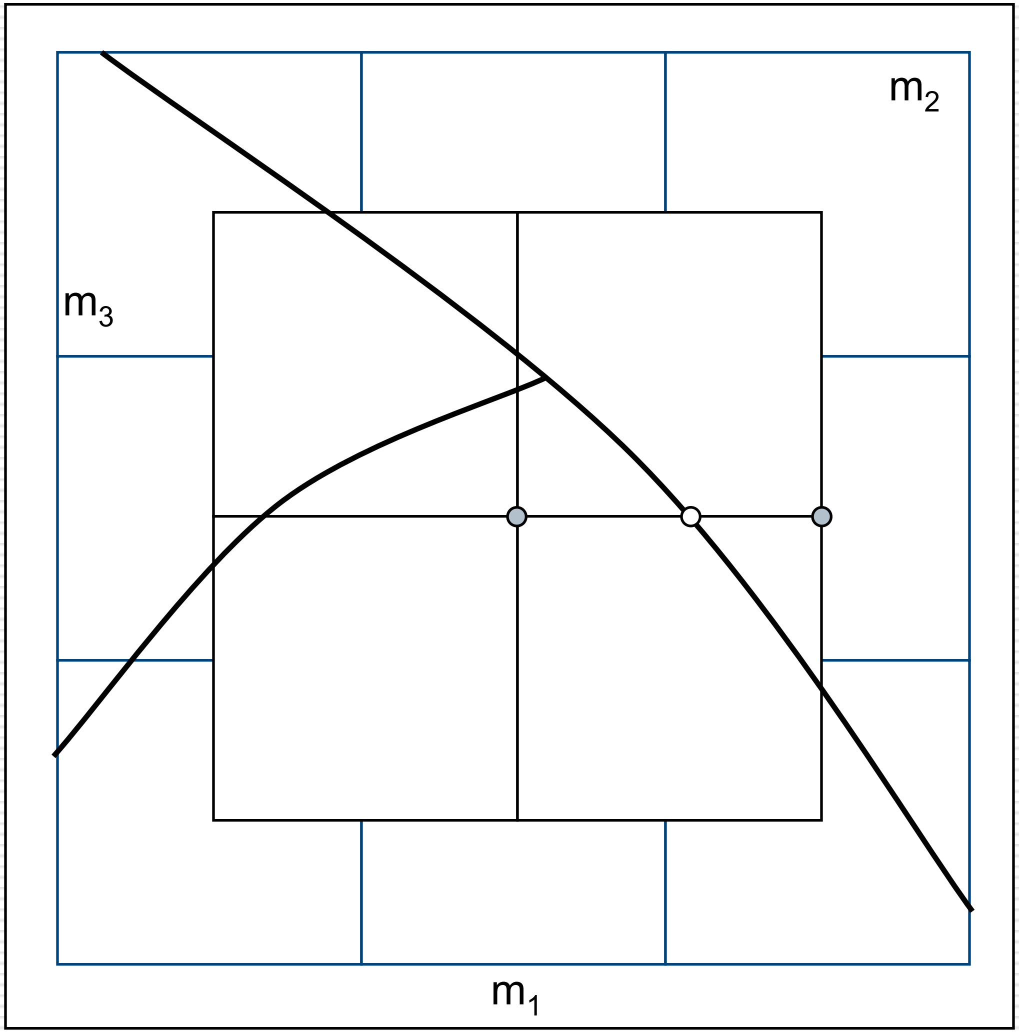
The Three-Material Case

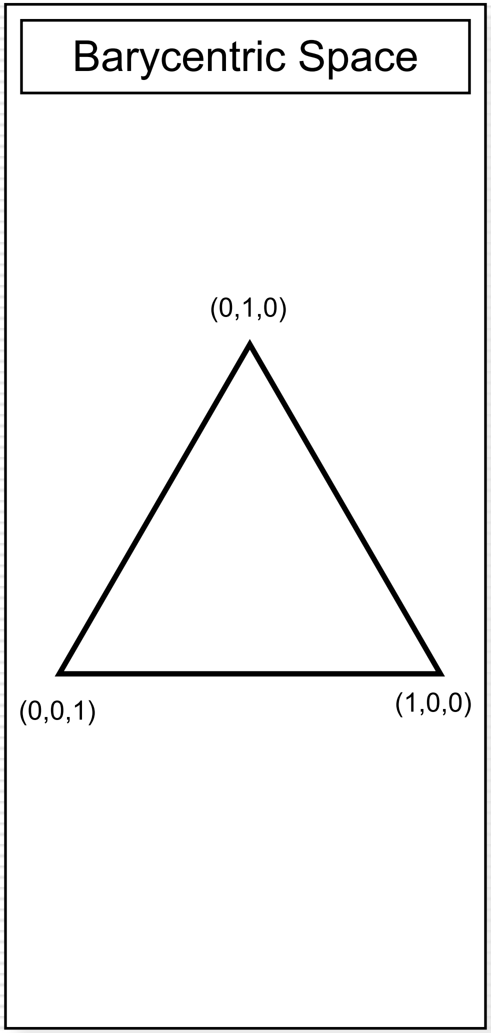


Each point on the dual grid has associated a barycentric coordinate (α_1, $\alpha_{2,}$ α_3),where α_1 +α_{2+} α_3 =1.

We would like to find the approximation represented by the Red line.

The Three-Material Case





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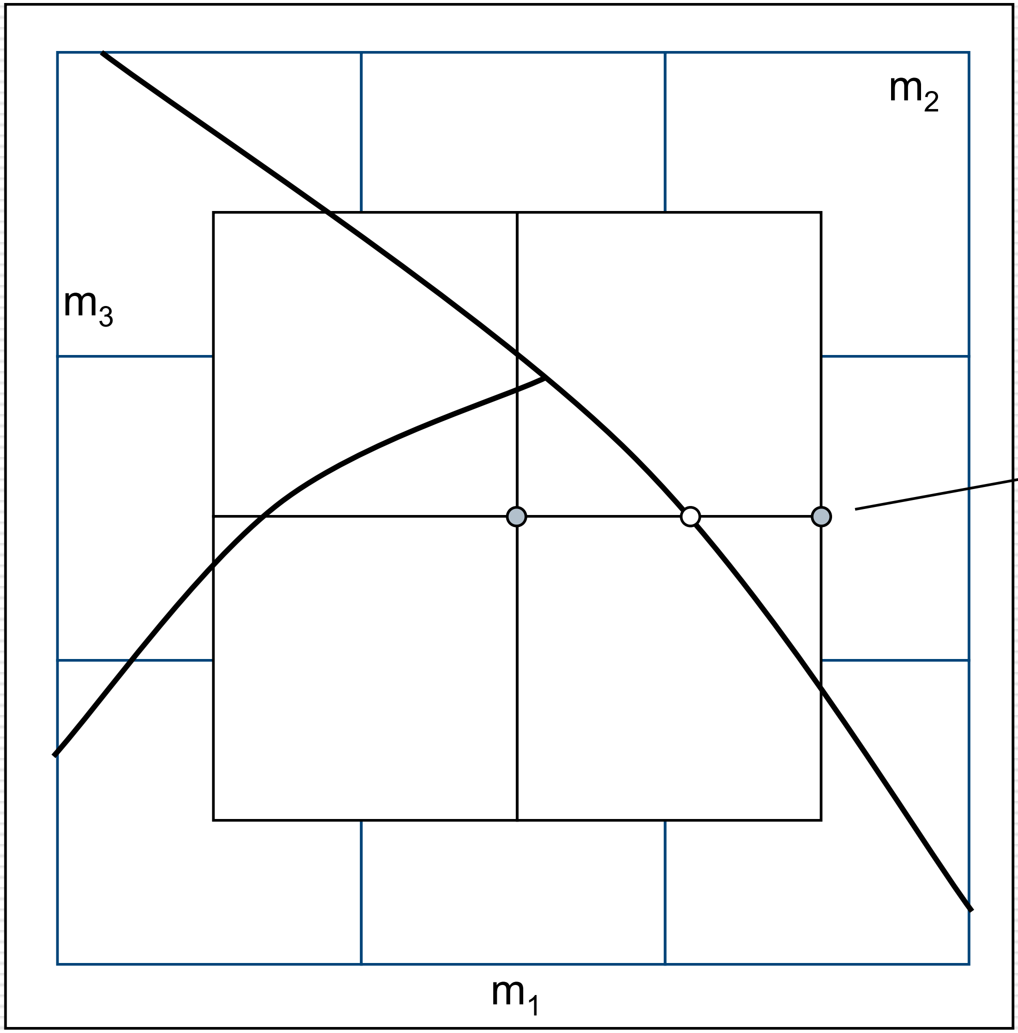

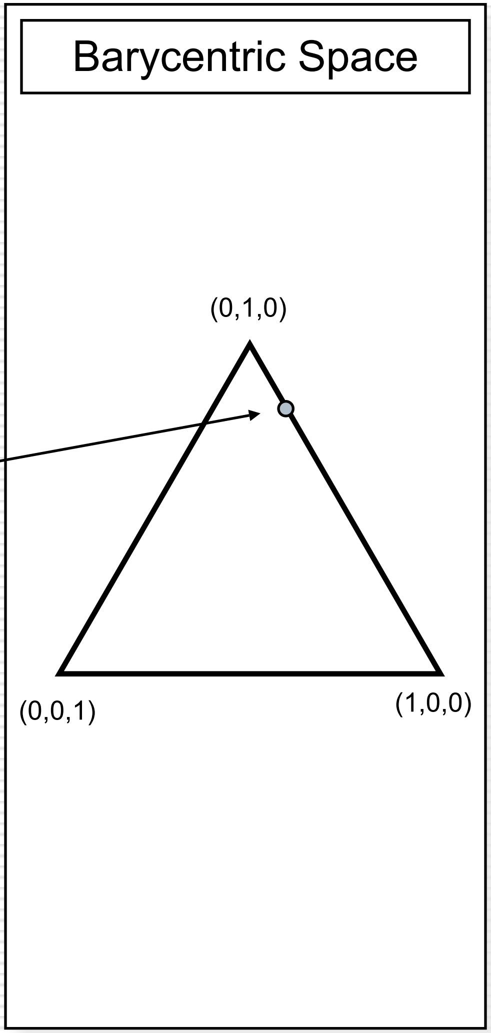

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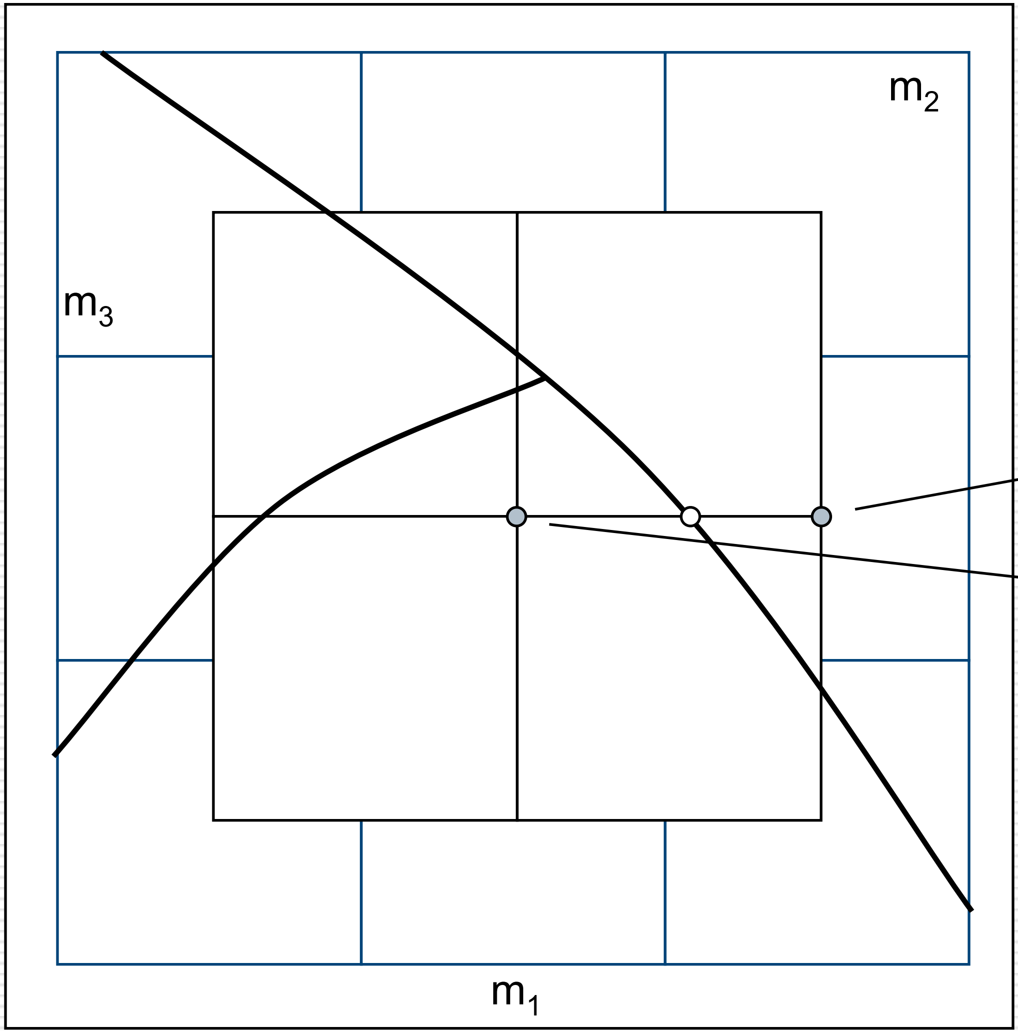

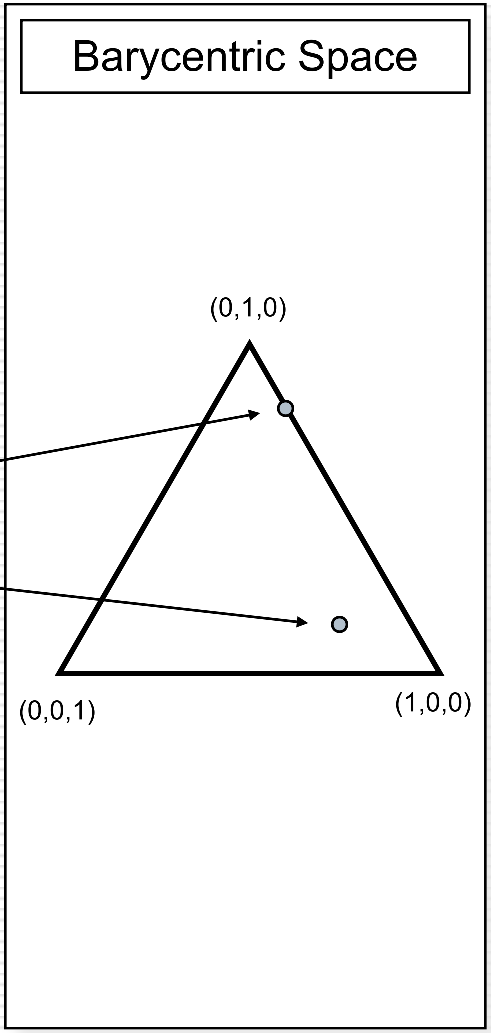

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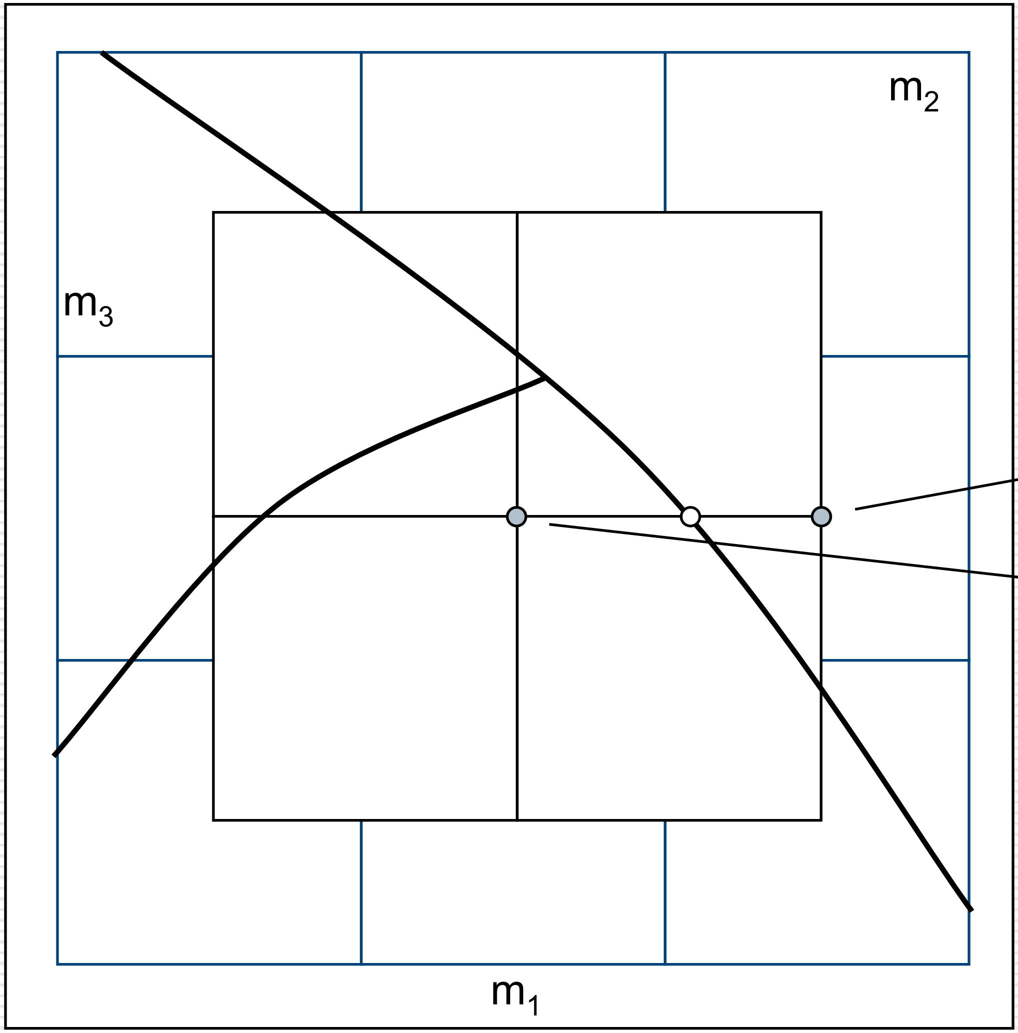

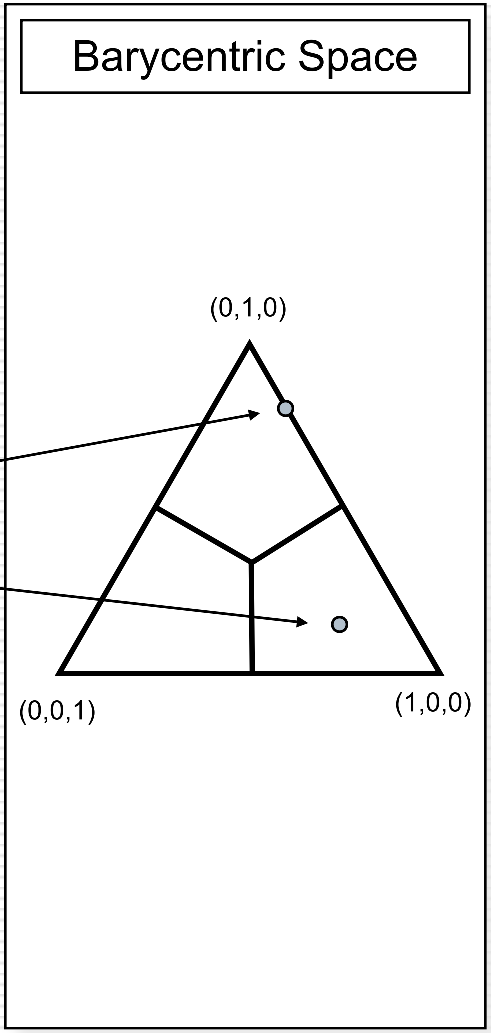

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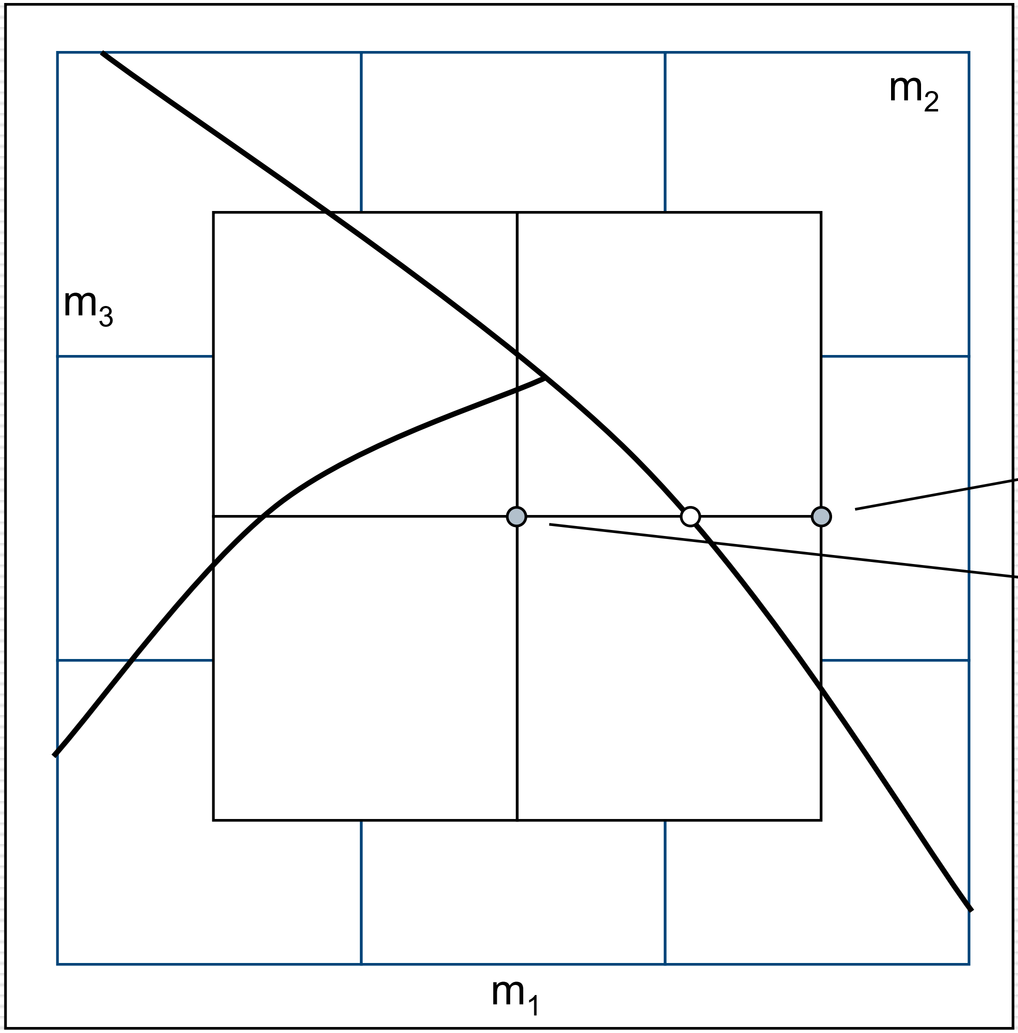

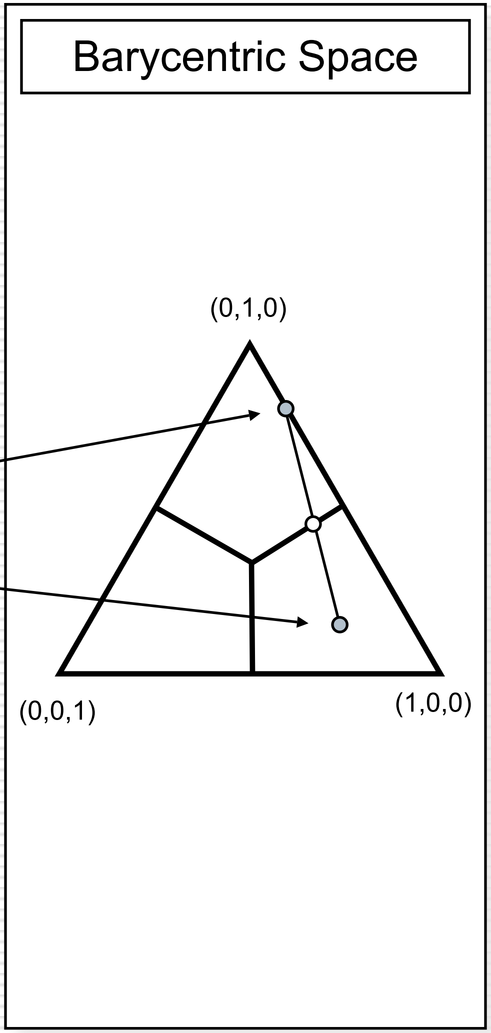

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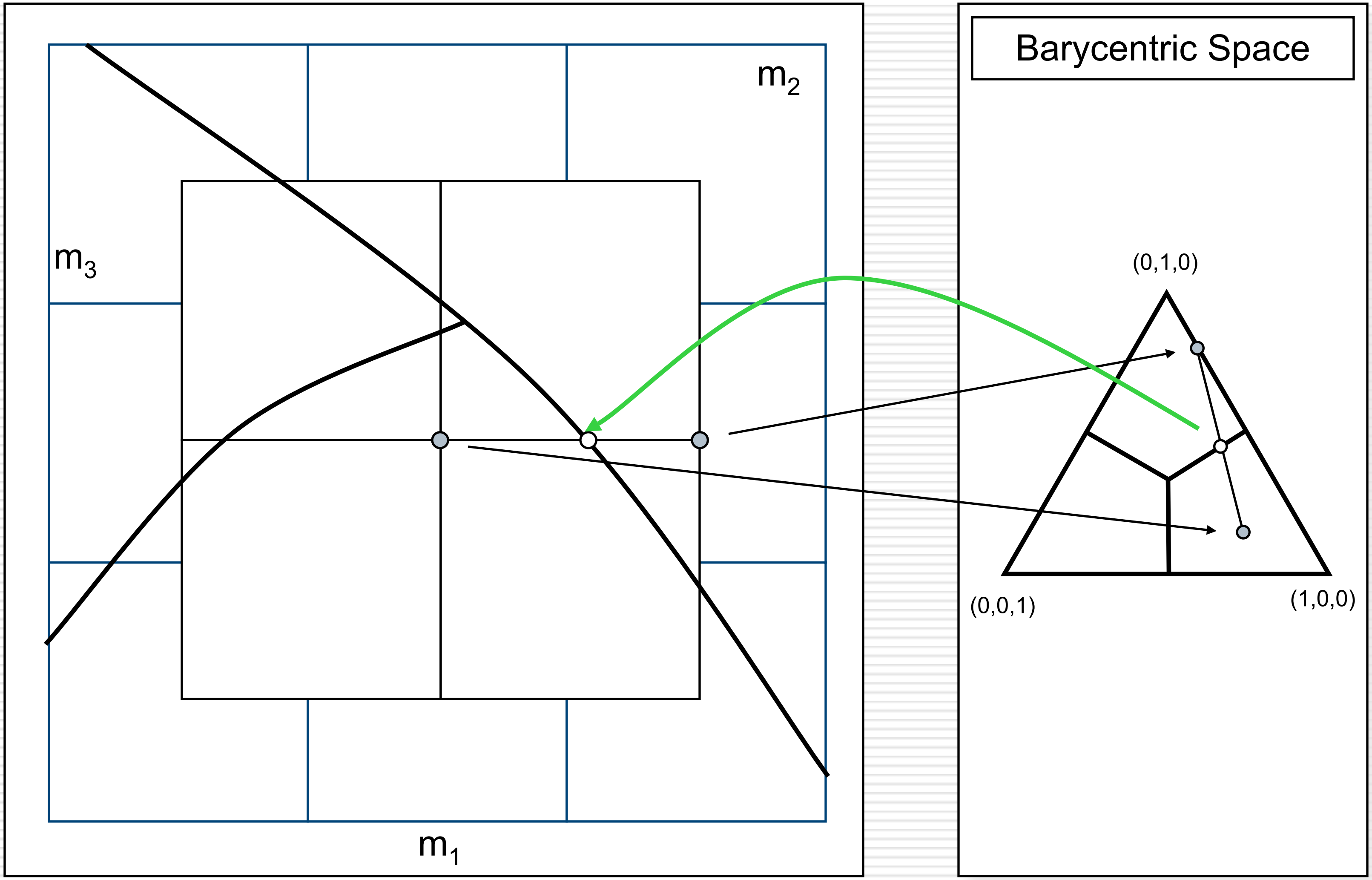

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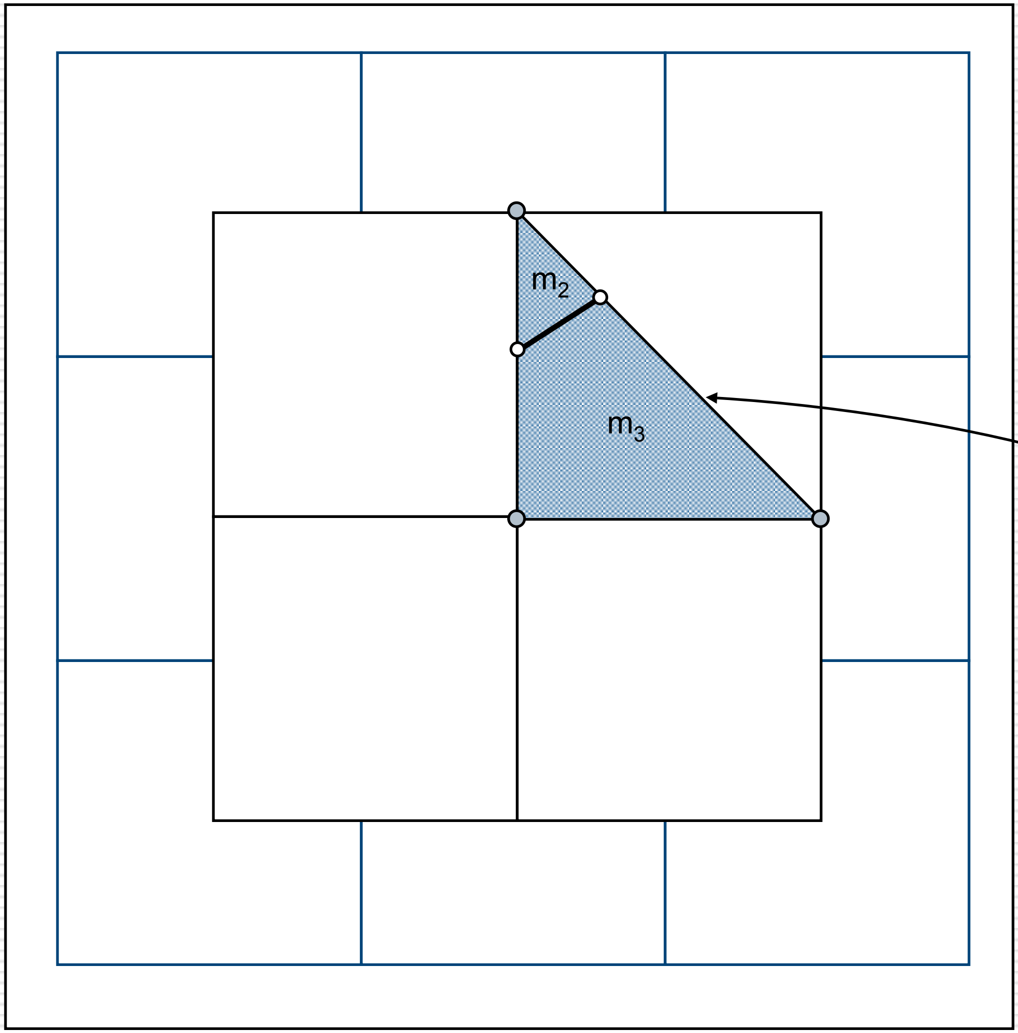
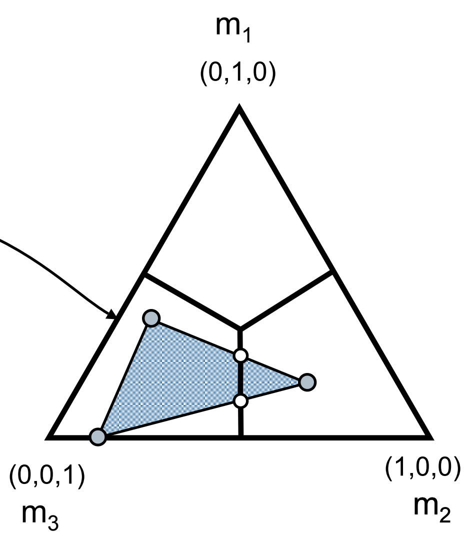


Barycentric Space



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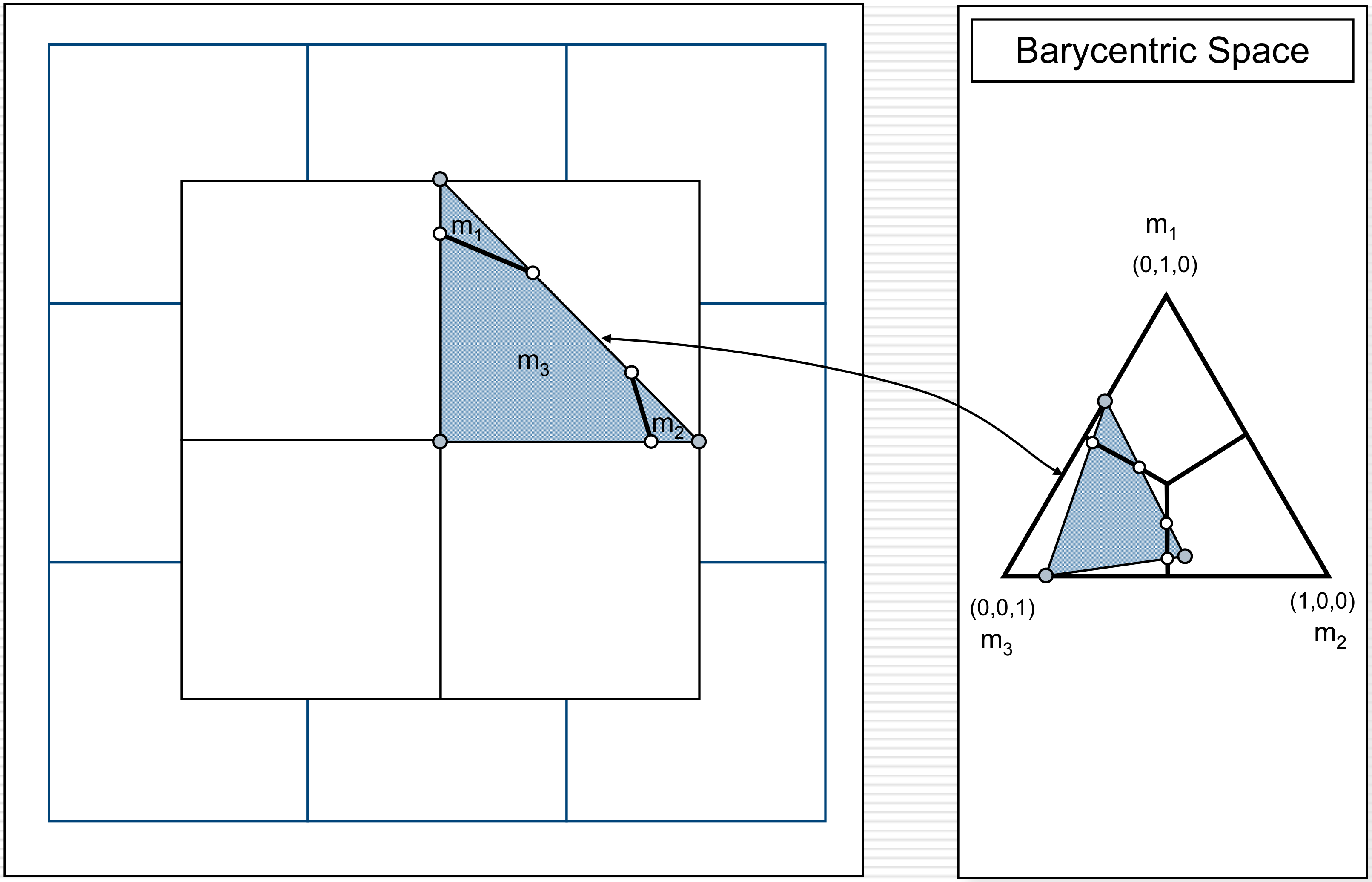

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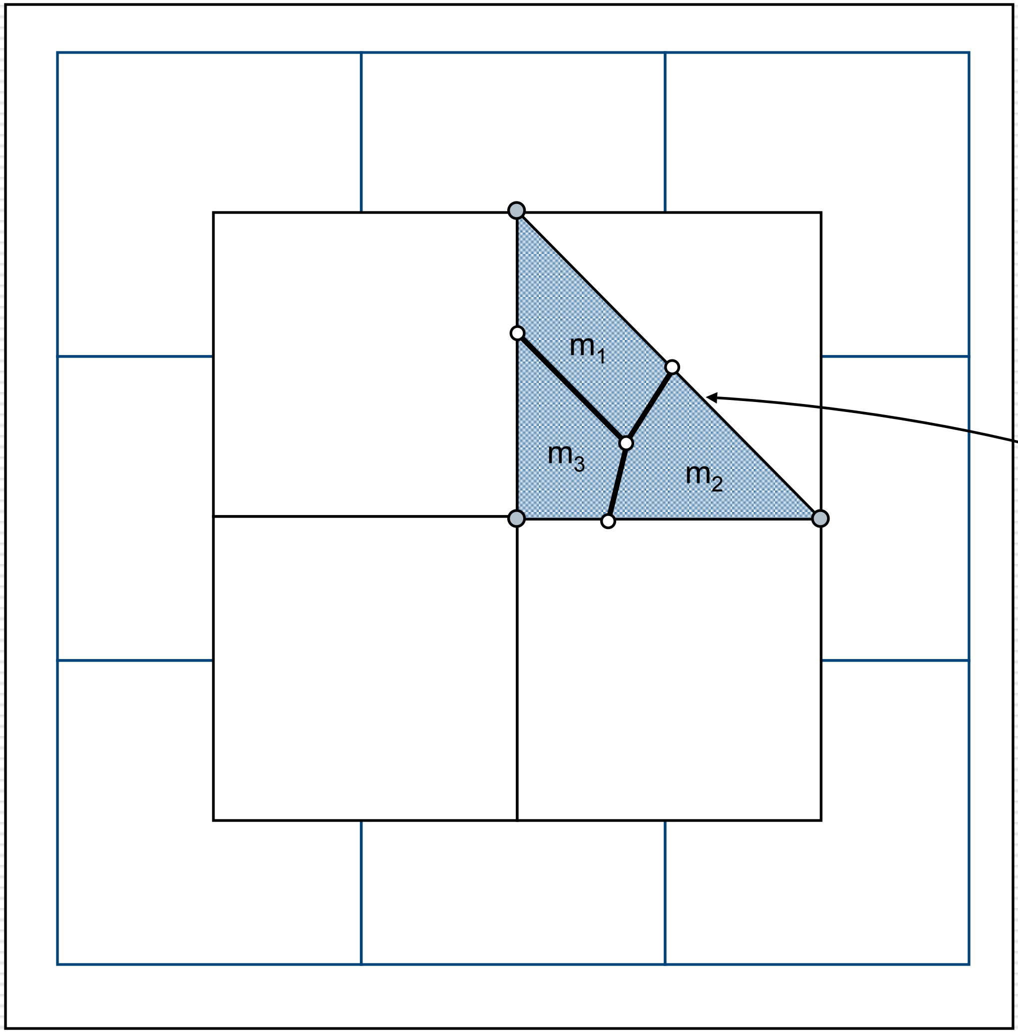

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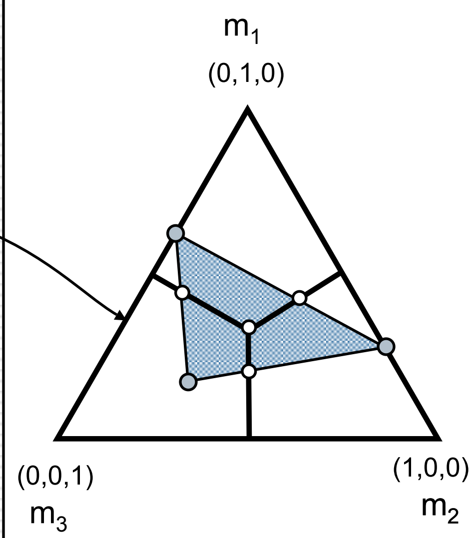
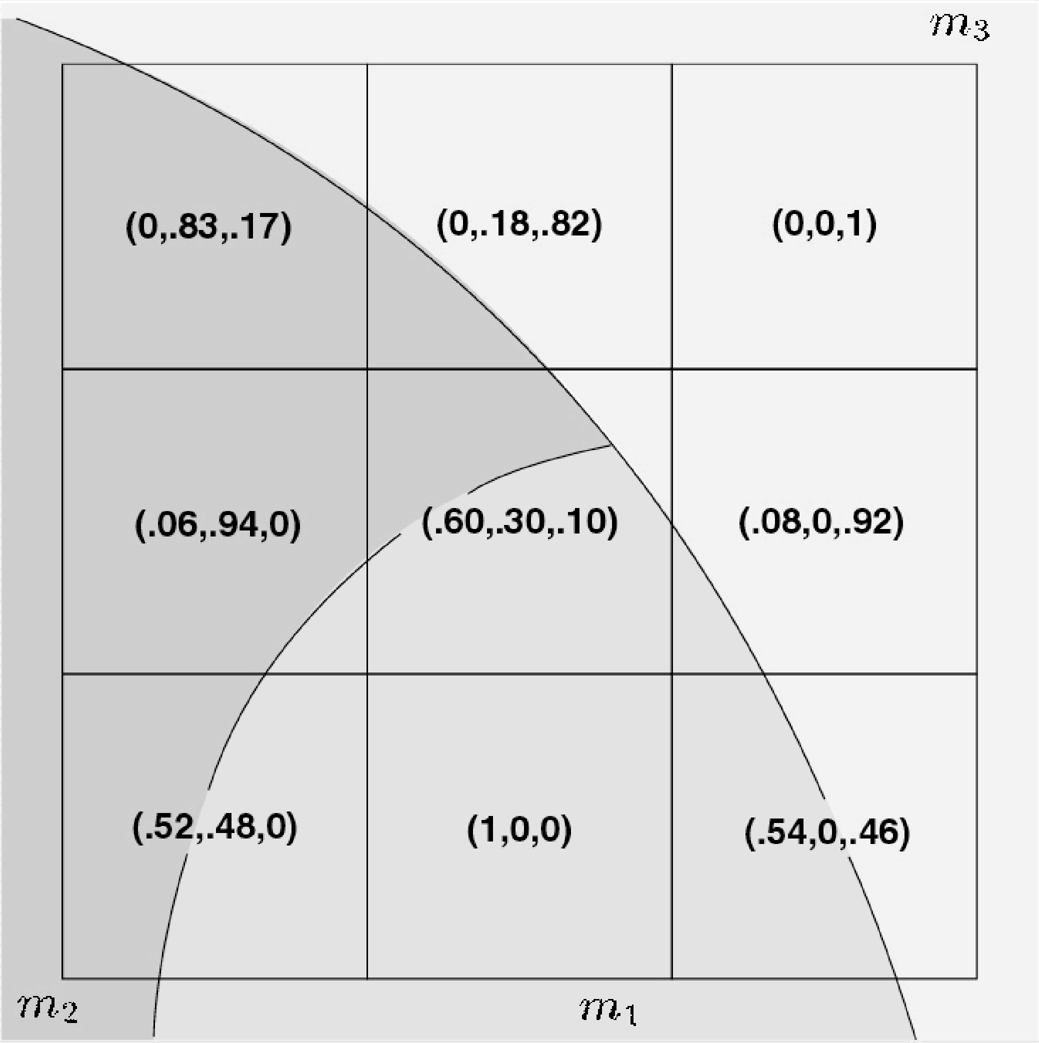


An Example



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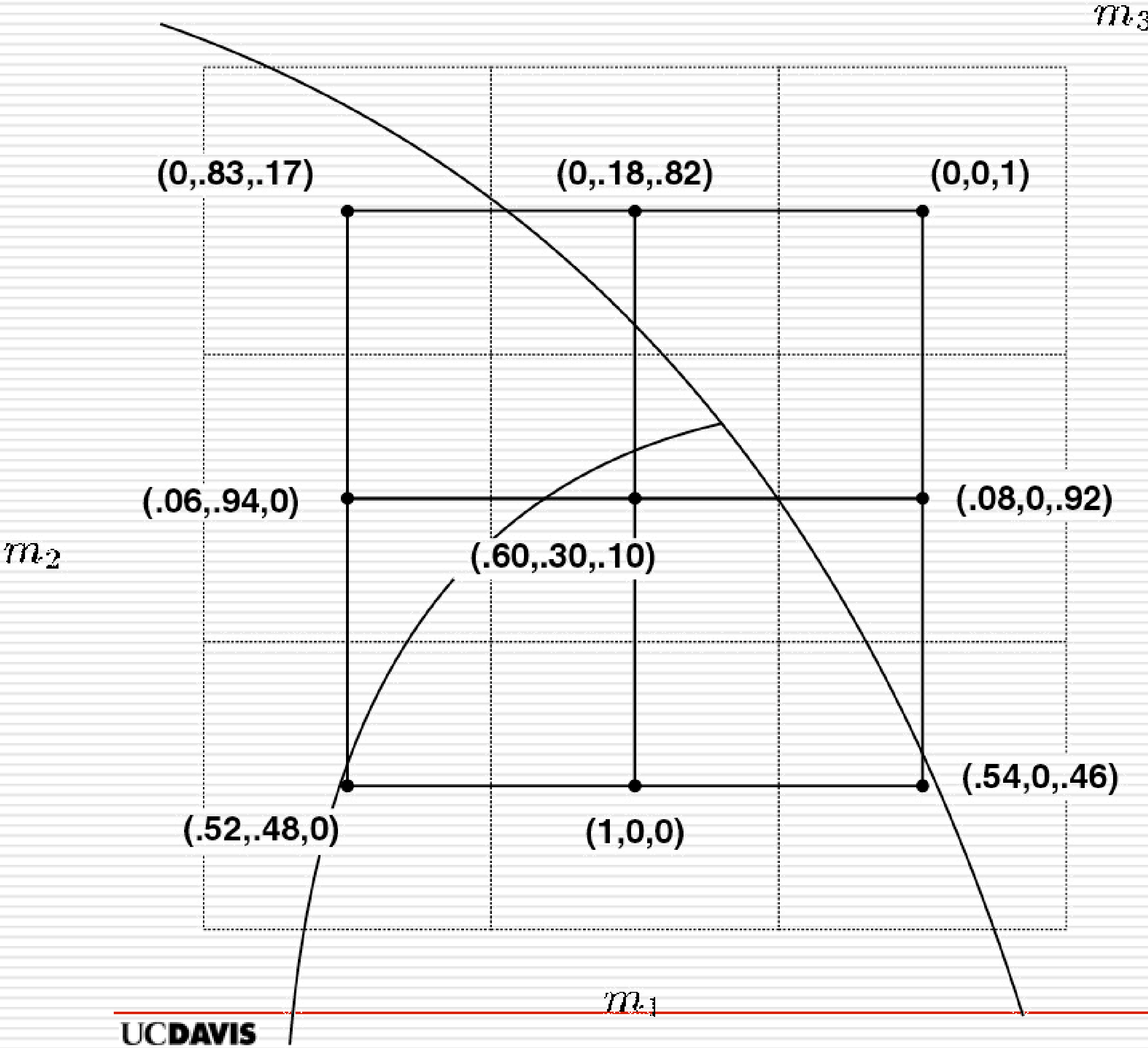
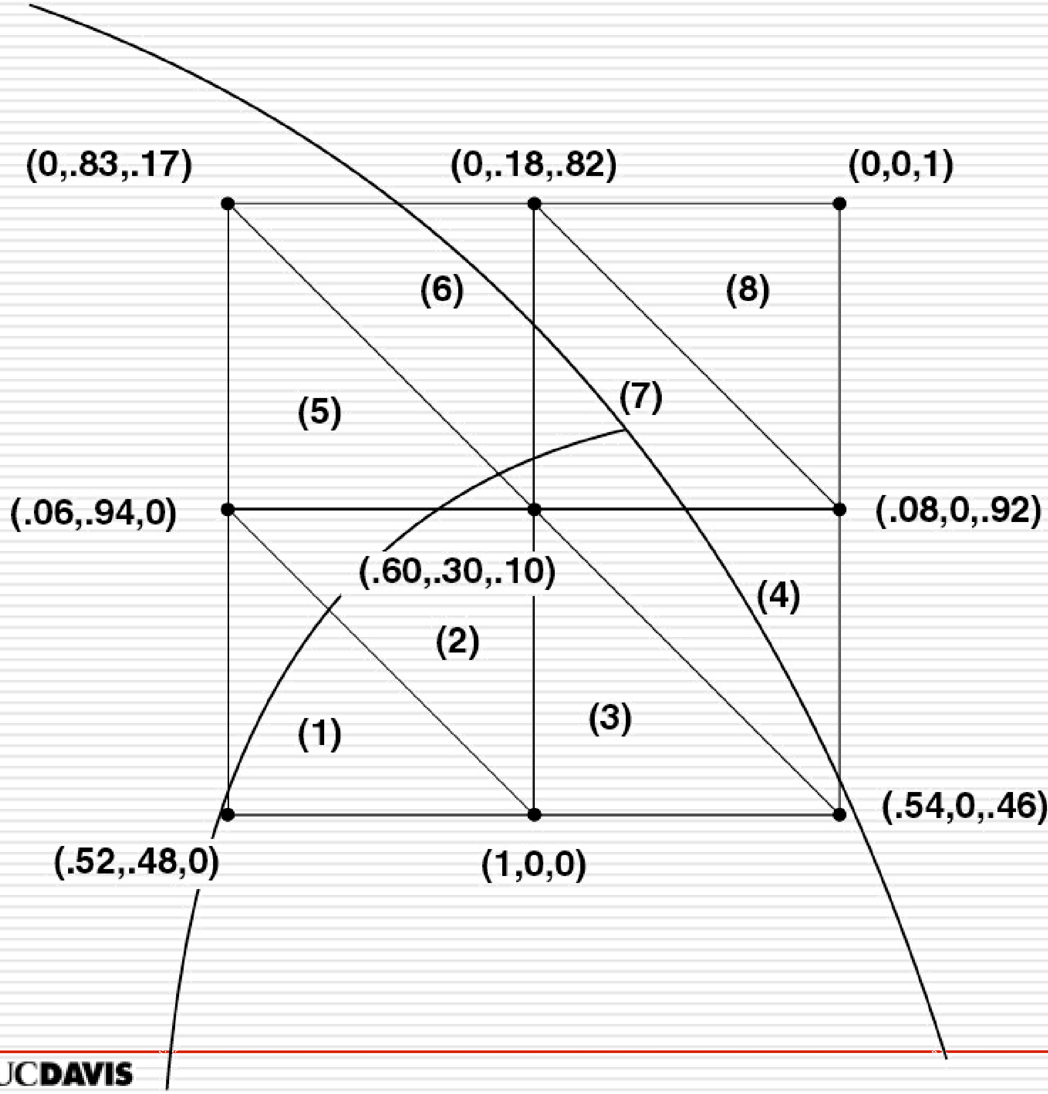


Changing to the dual grid. Each grid point has associated a barycentric coordinate.

An Example

Triangulating the grid.



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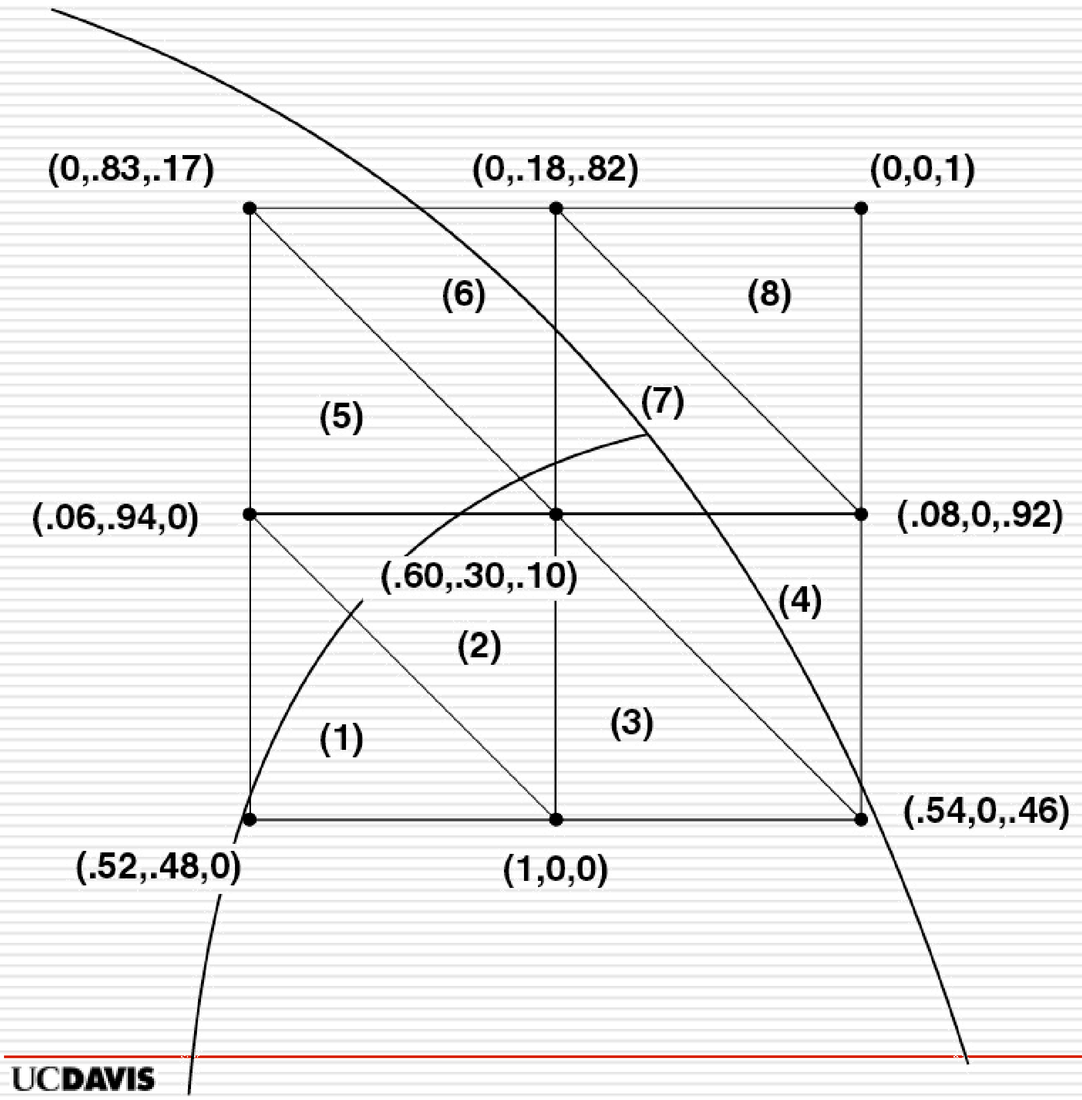
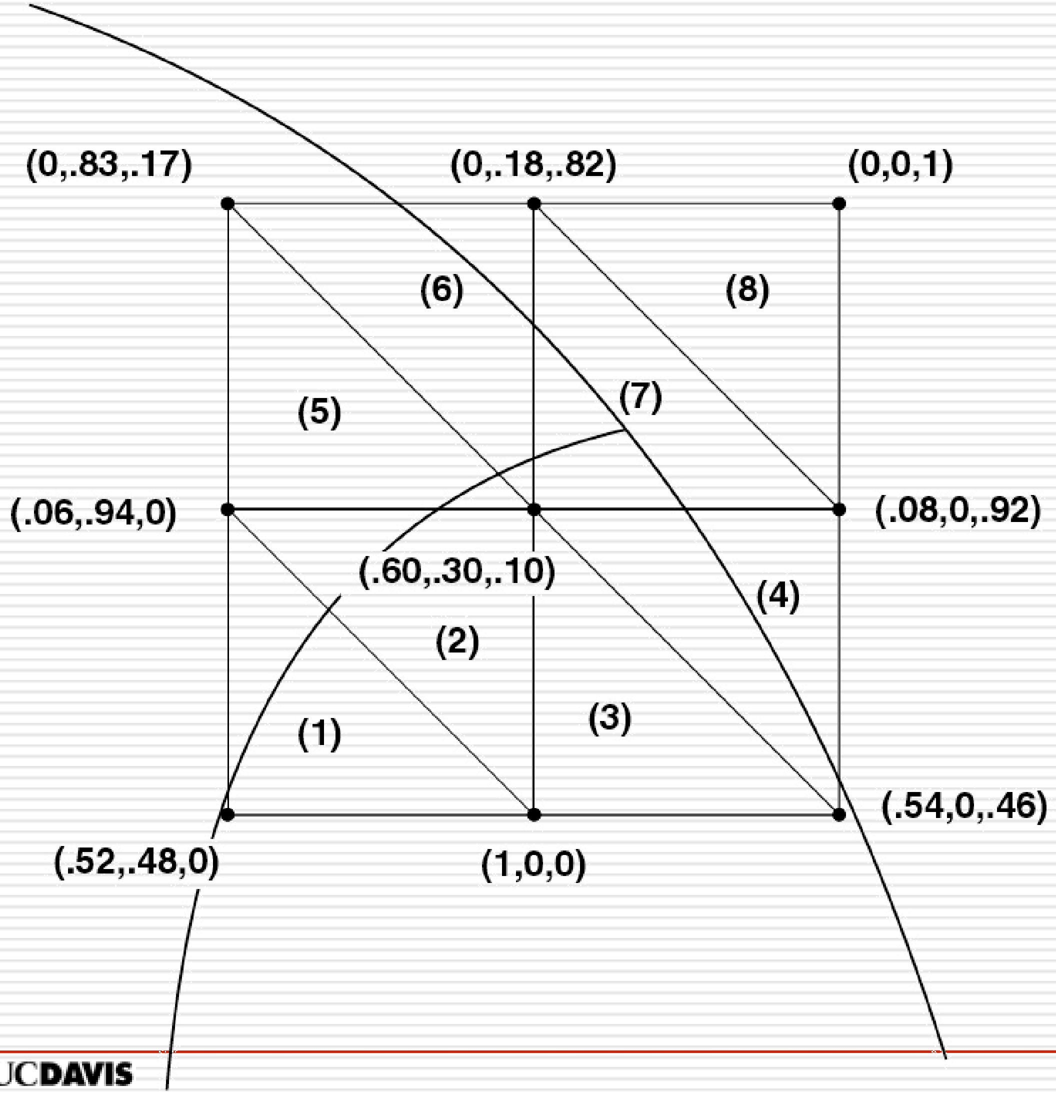


Triangulating the grid.

Triangles 3 and 8 contain no boundaries.

An Example



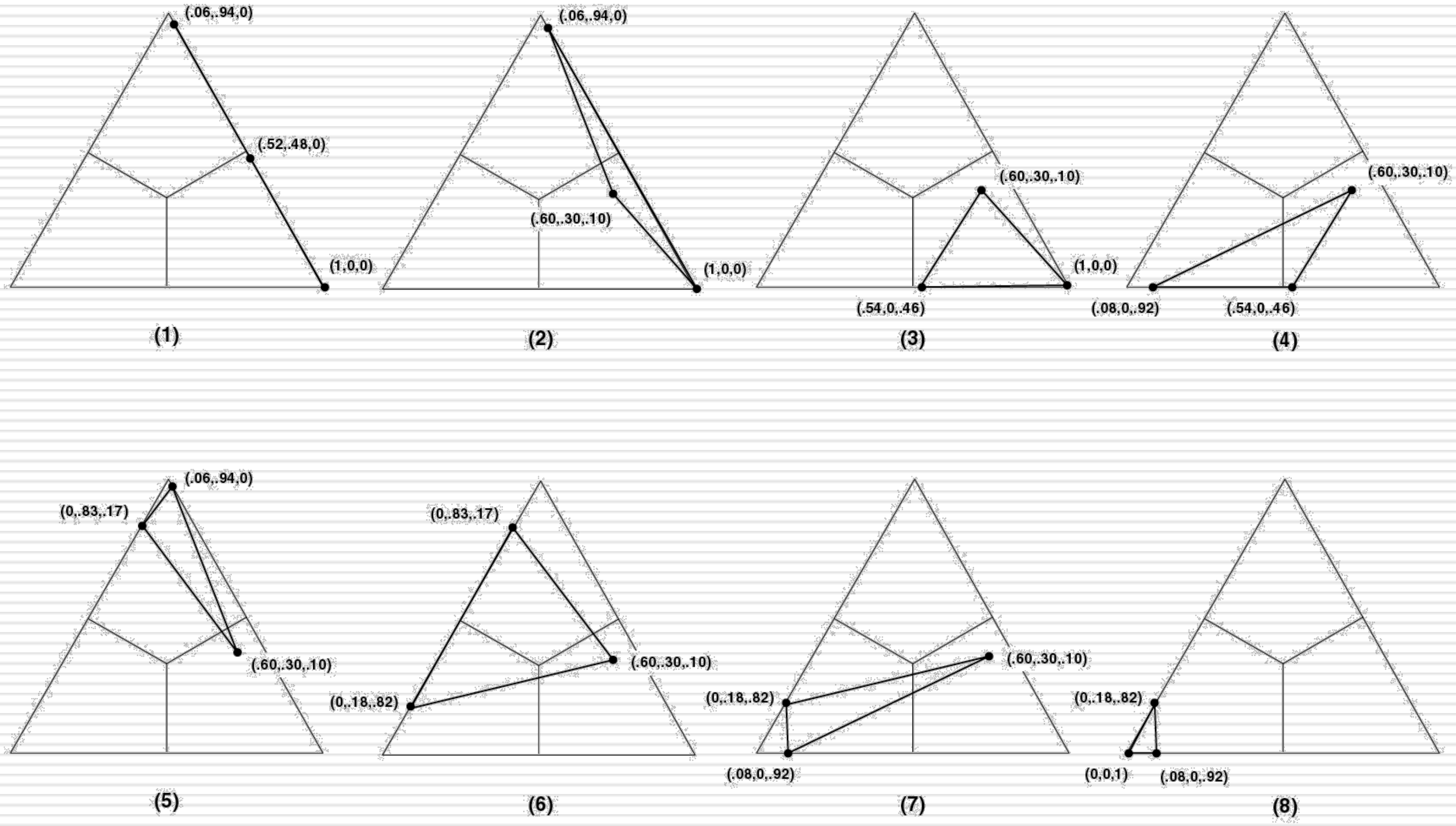
Triangulating the grid.

Triangles 3 and 8 contain no boundaries.

The three materials meet in triangle 7.

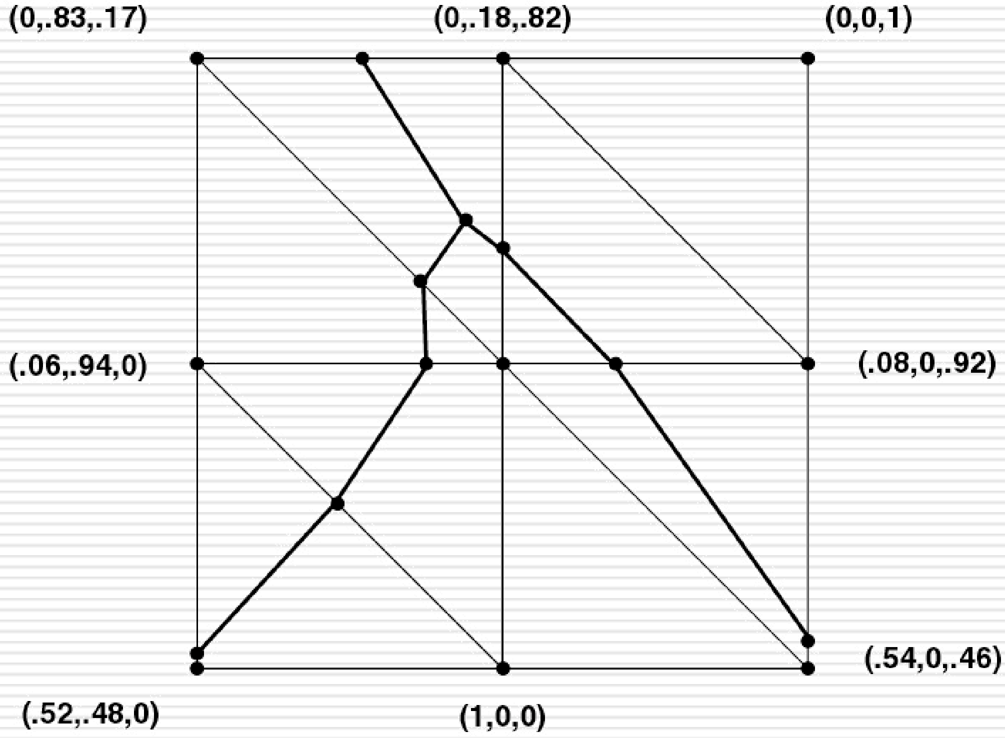
An Example

In Barycentric Space



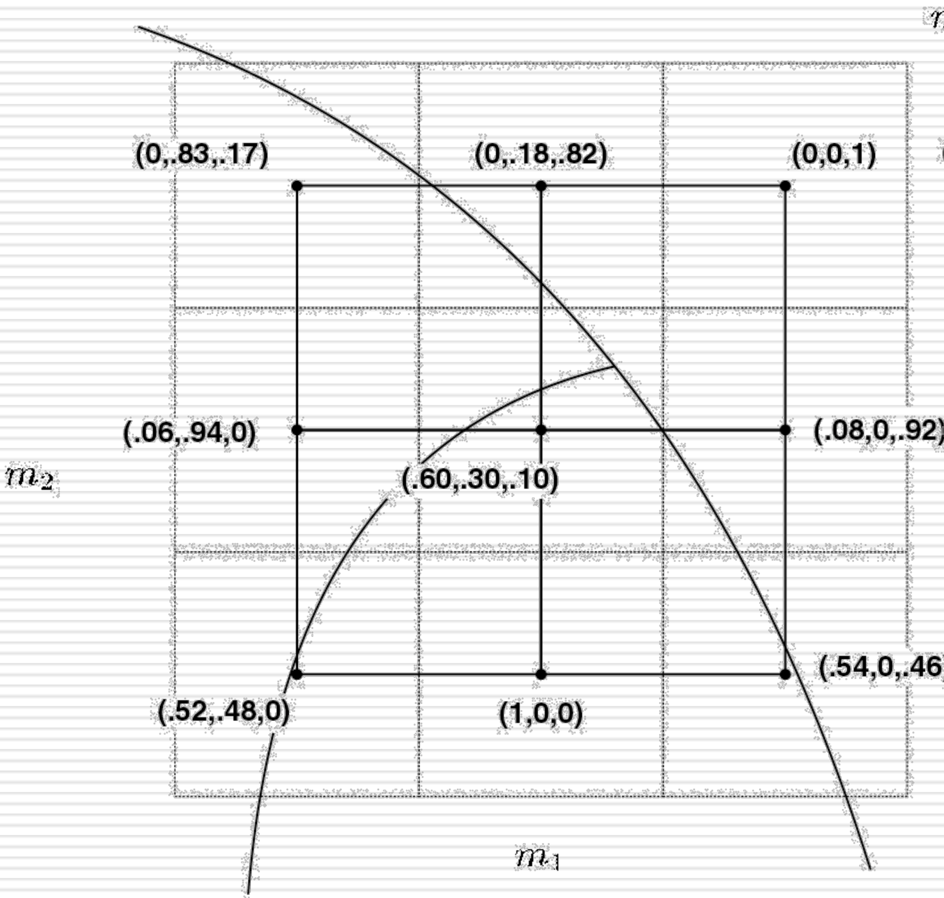
An Example

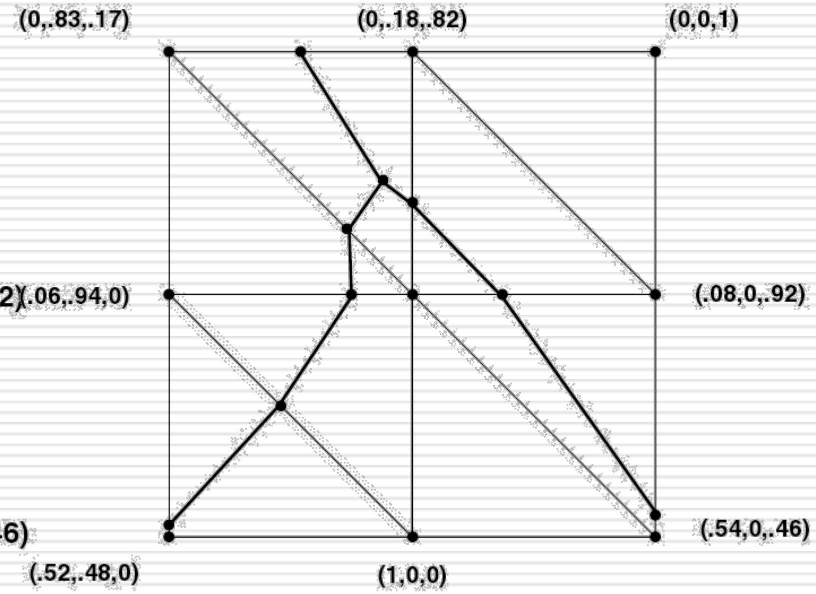
This is the approximation to the material boundaries.



An Example

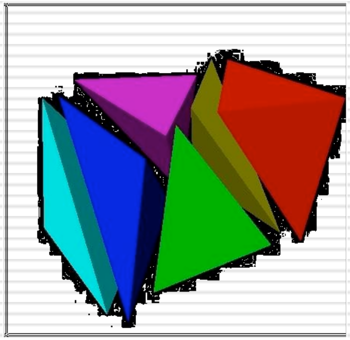
Comparison





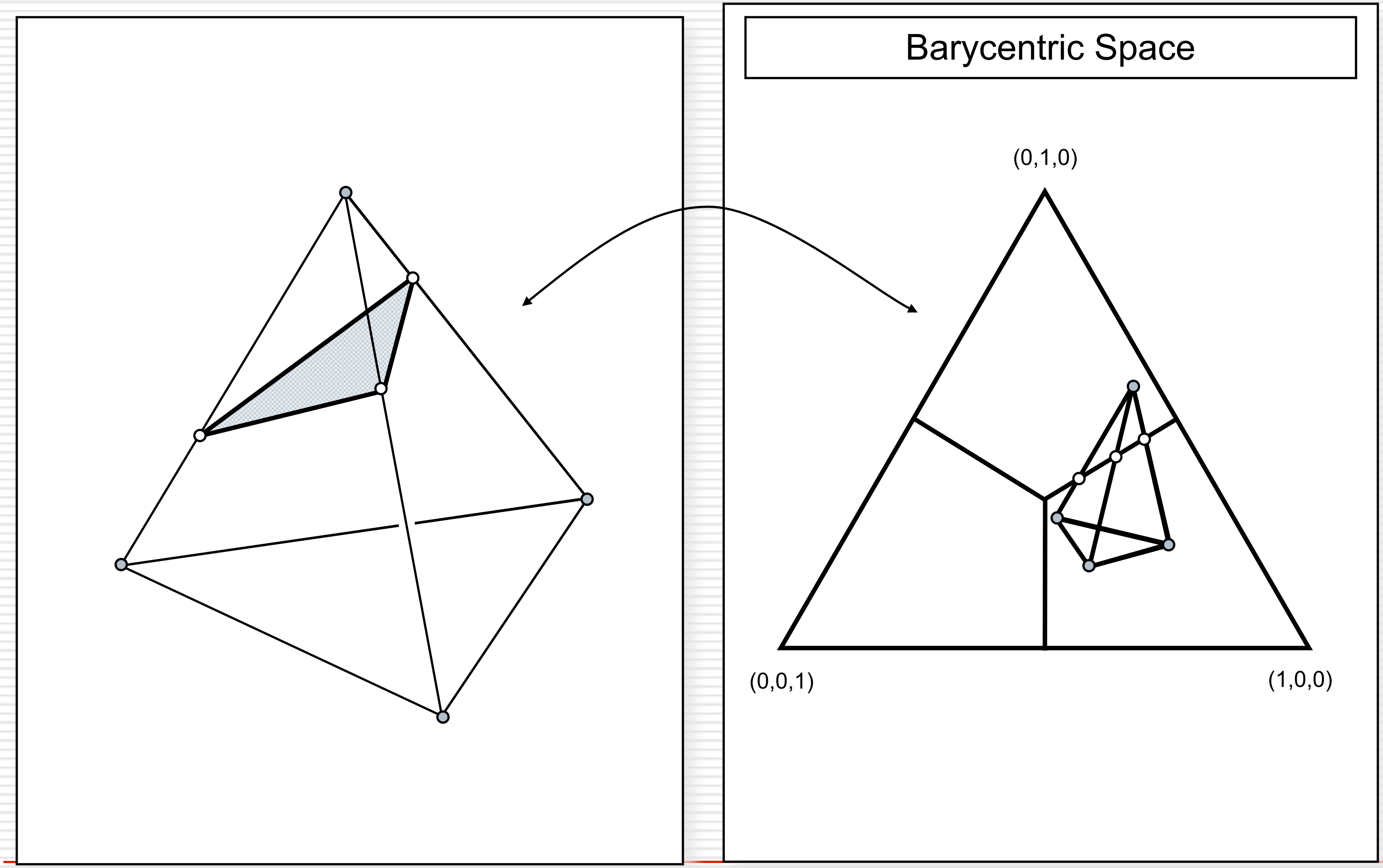
Three-dimensional Grids

- Move to the dual grid.
- Split each cell into six tetrahedra (CMK splits)

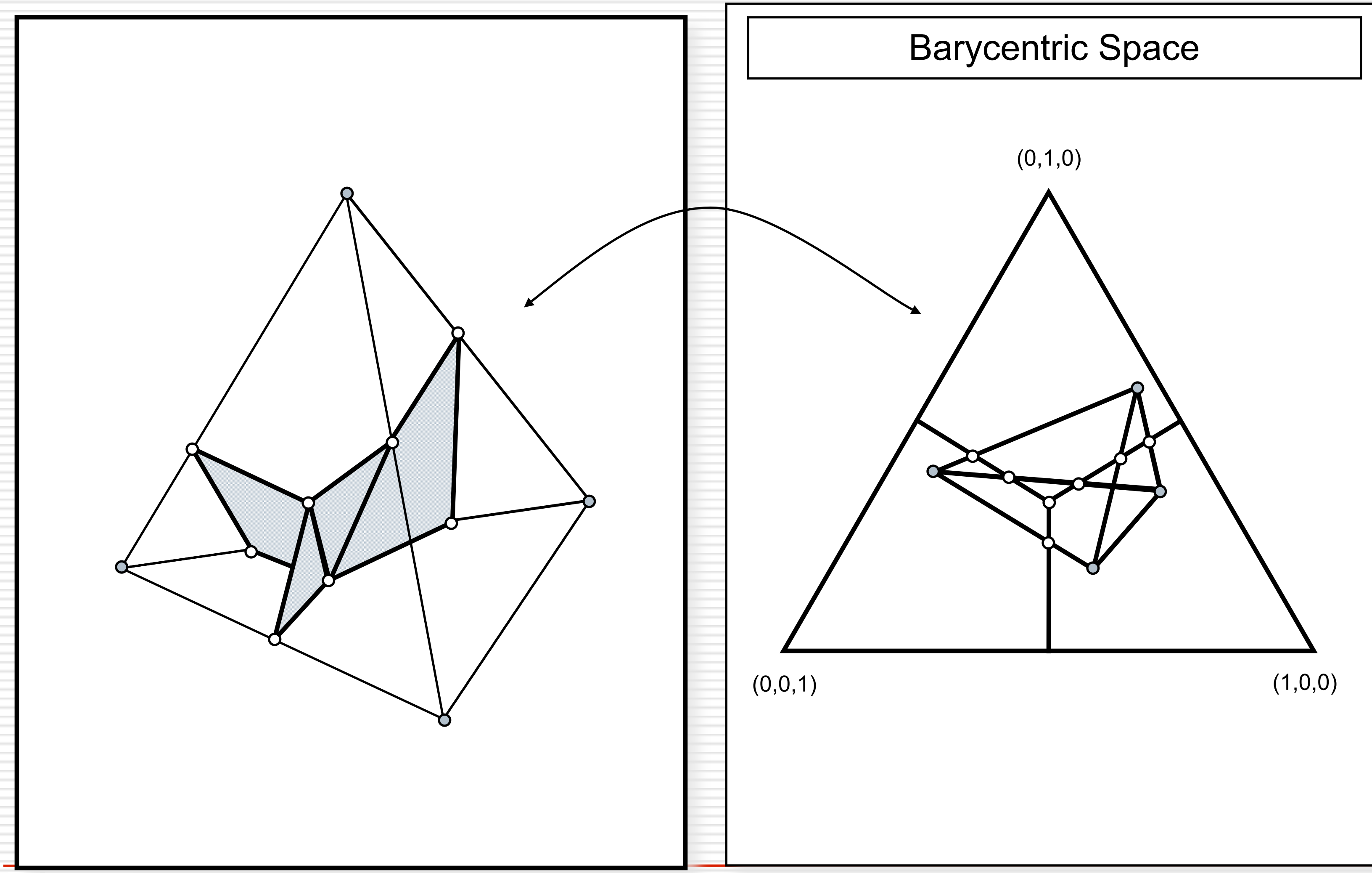


- Map each tetrahedron into barycentric space and calculate intersections.

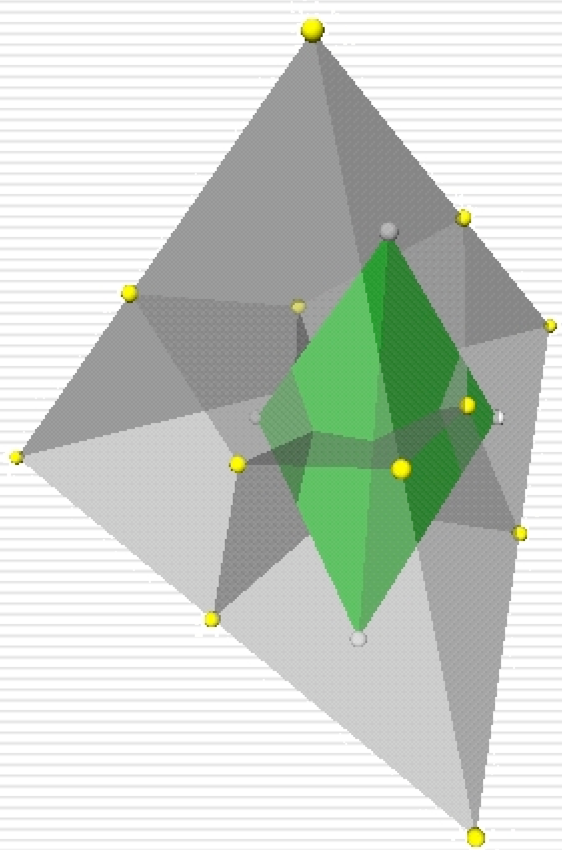
The Three-Material Case



The Three-Material Case



The Four-Material Case



Barycentric Space with an embedded tetrahedron.

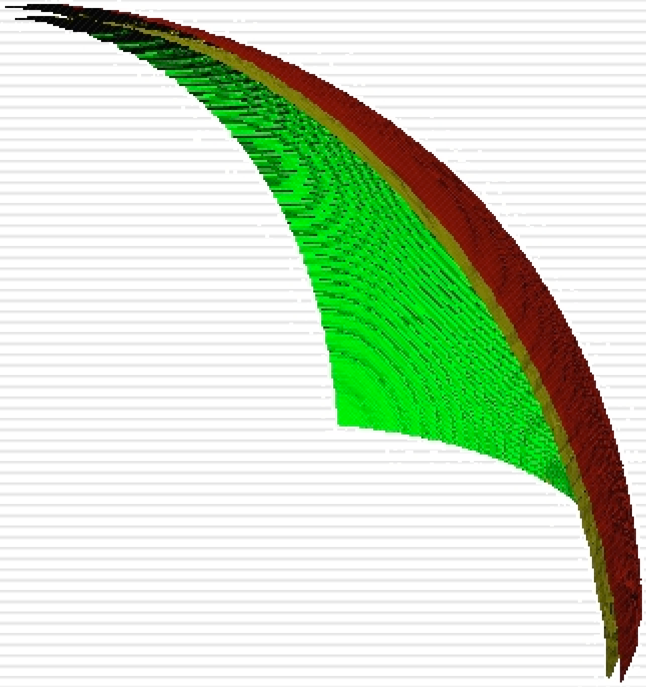
It is just a clipping problem to determine the boundaries

n-Material Case

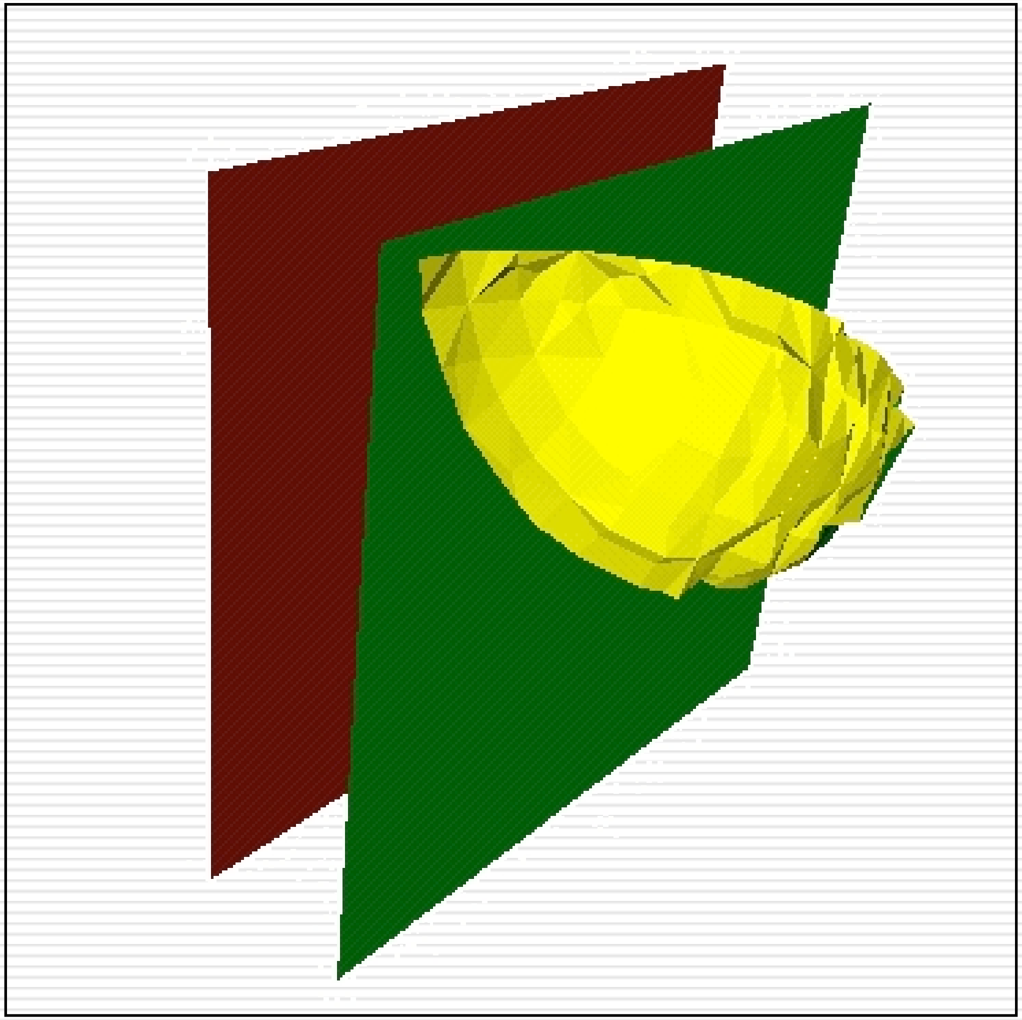
- In most meshes, the majority of the cells are a single material.
- The three- and four-material case happens rarely
- The n-material case also happens rarely.
  - But the clipping strategy works regardless of the number of materials.
- The n-material case may construct n-1 boundaries in a tetrahedron

Results – Concentric Shells

The data set is 64x64x64 and contains three materials.



Results – Ball Striking a Plate



The data set is 53x23x23 and contains four materials.

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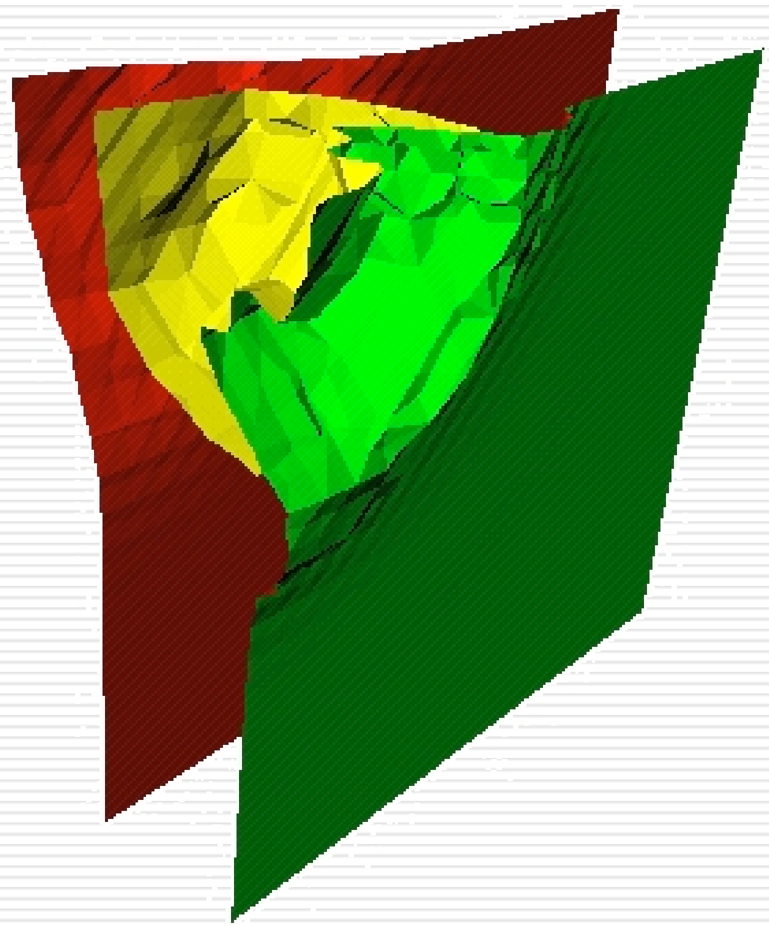

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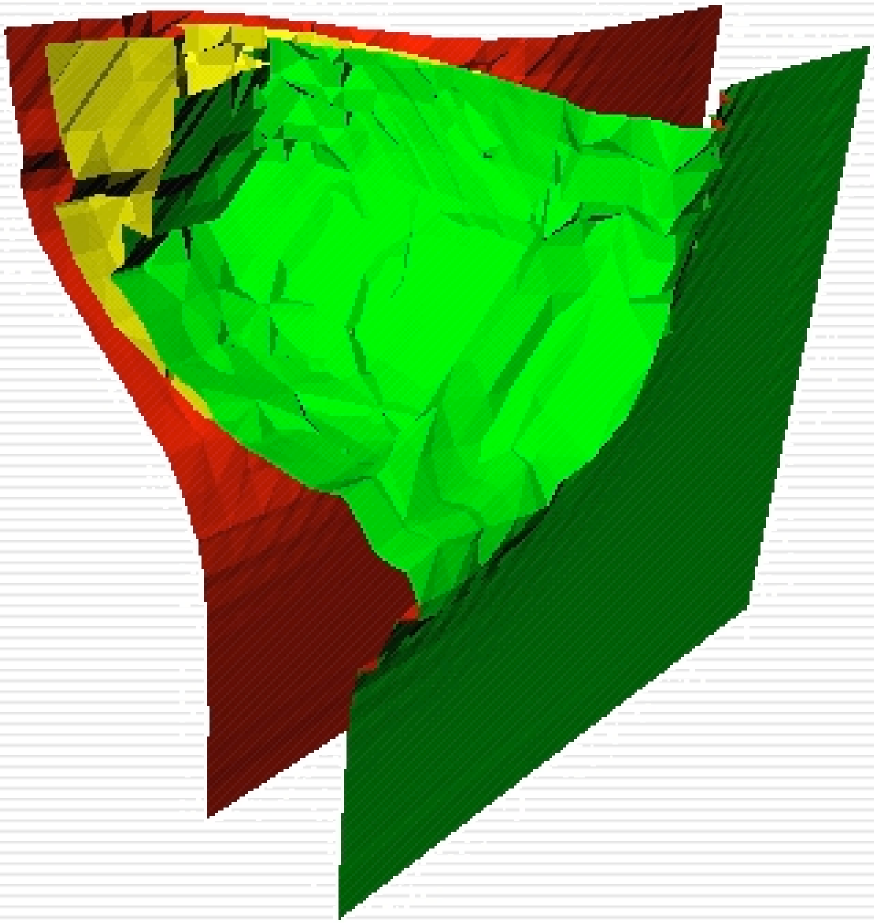

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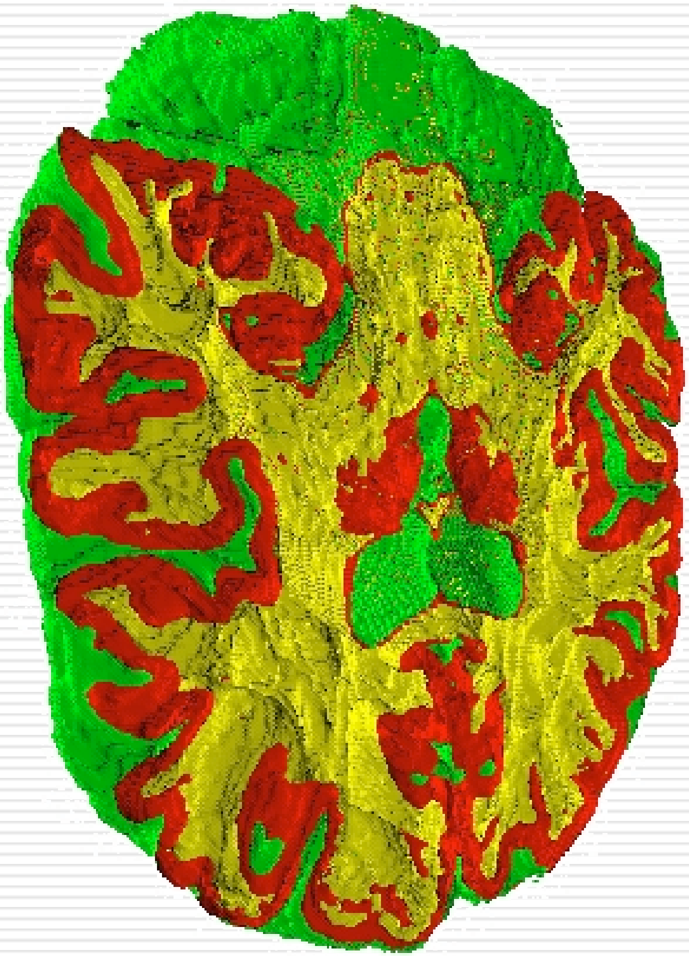
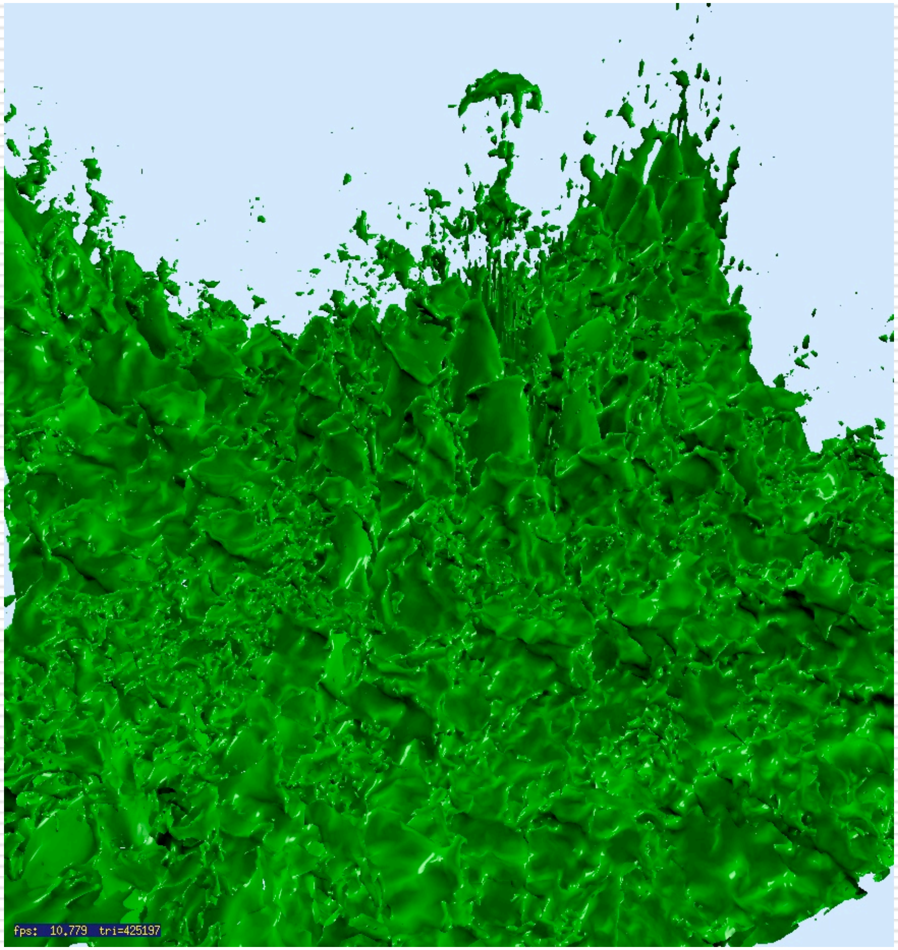
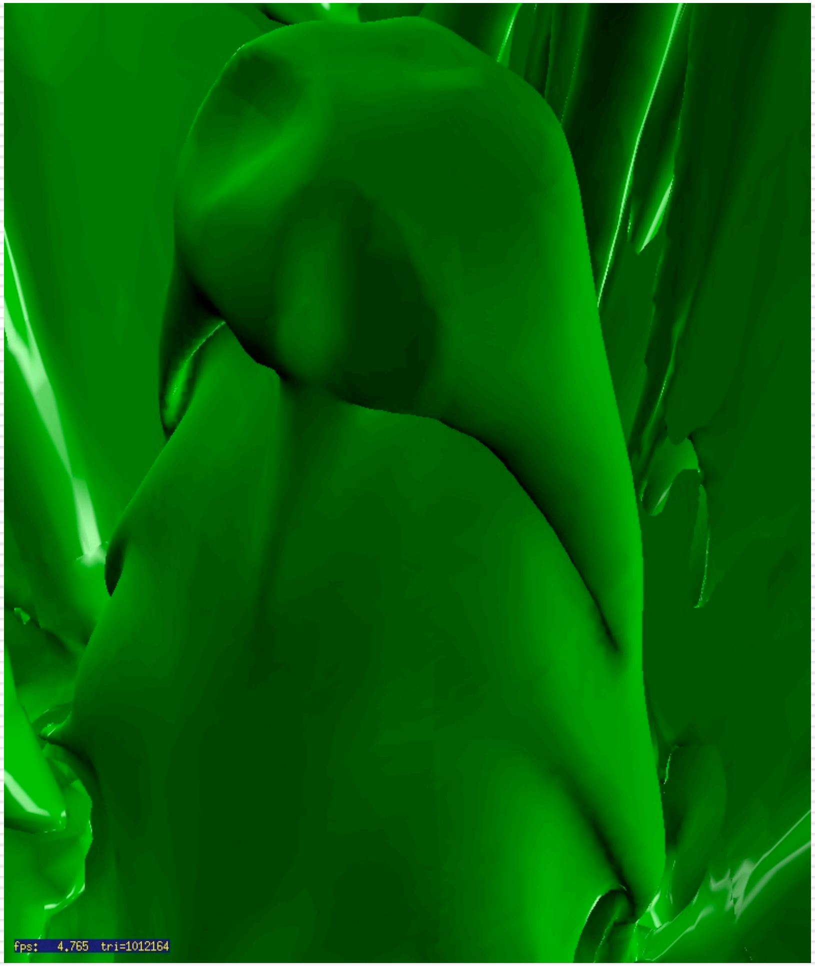
Results



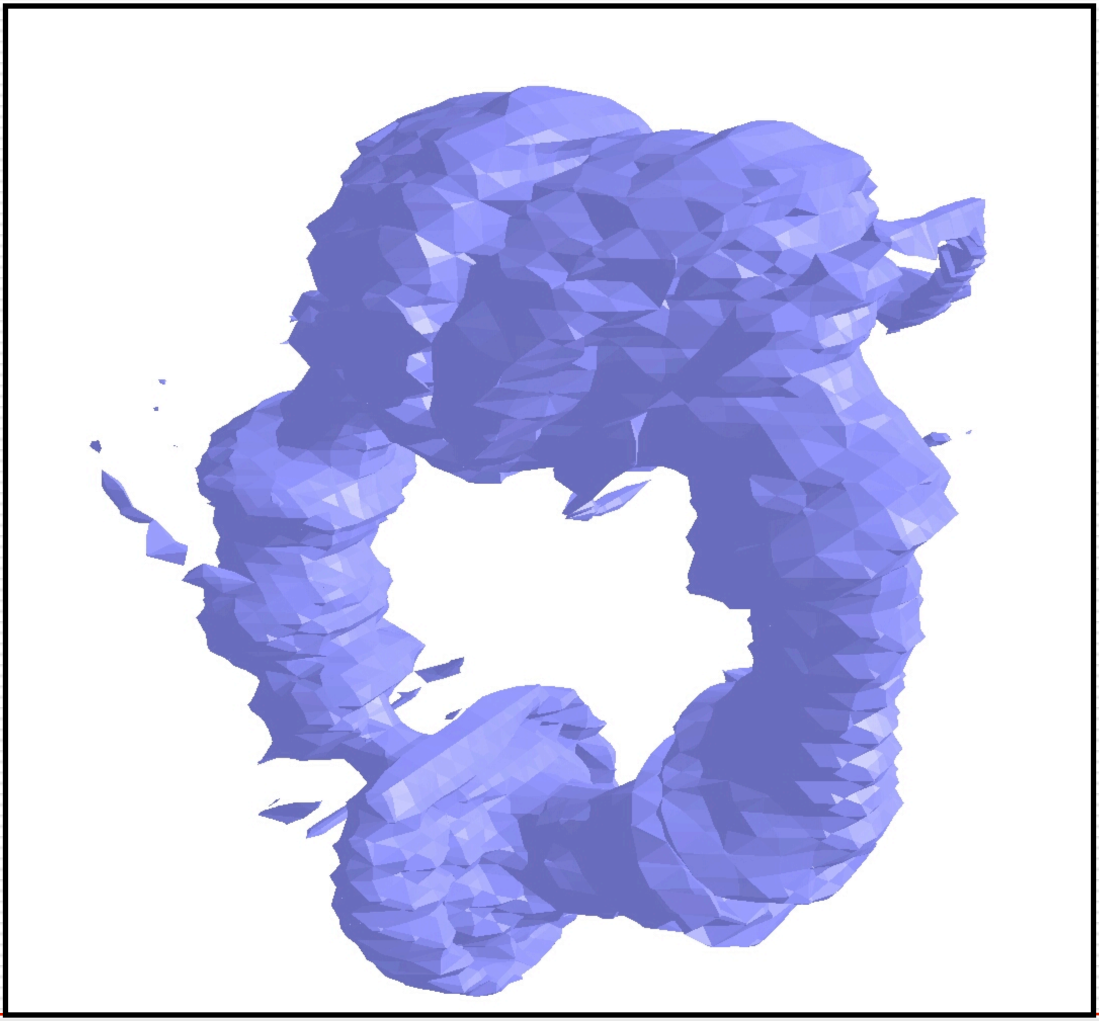
The data set is 256x256x128 and contains three materials (white matter, gray matter and other)

It doesn't scale!

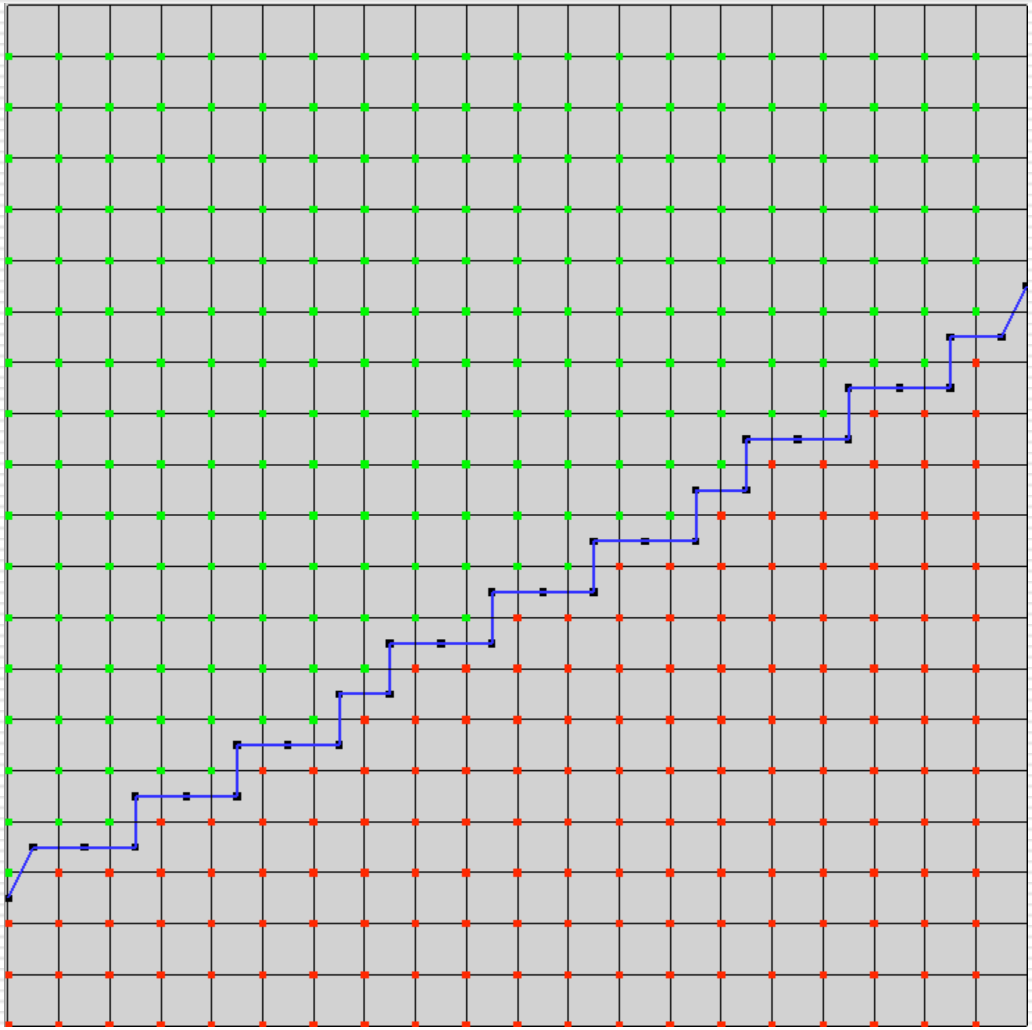




Applications -- Separating Surfaces



New Methods -- Dual Contouring Approaches



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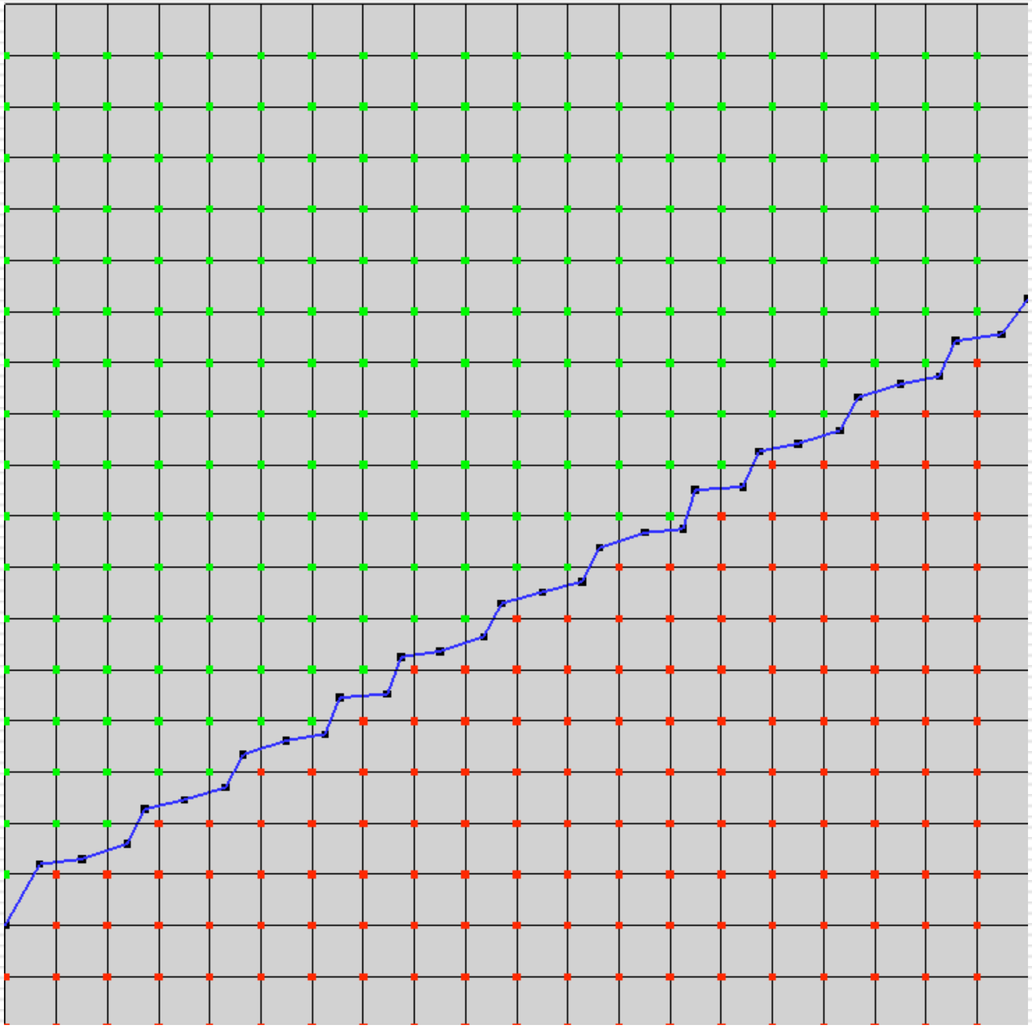

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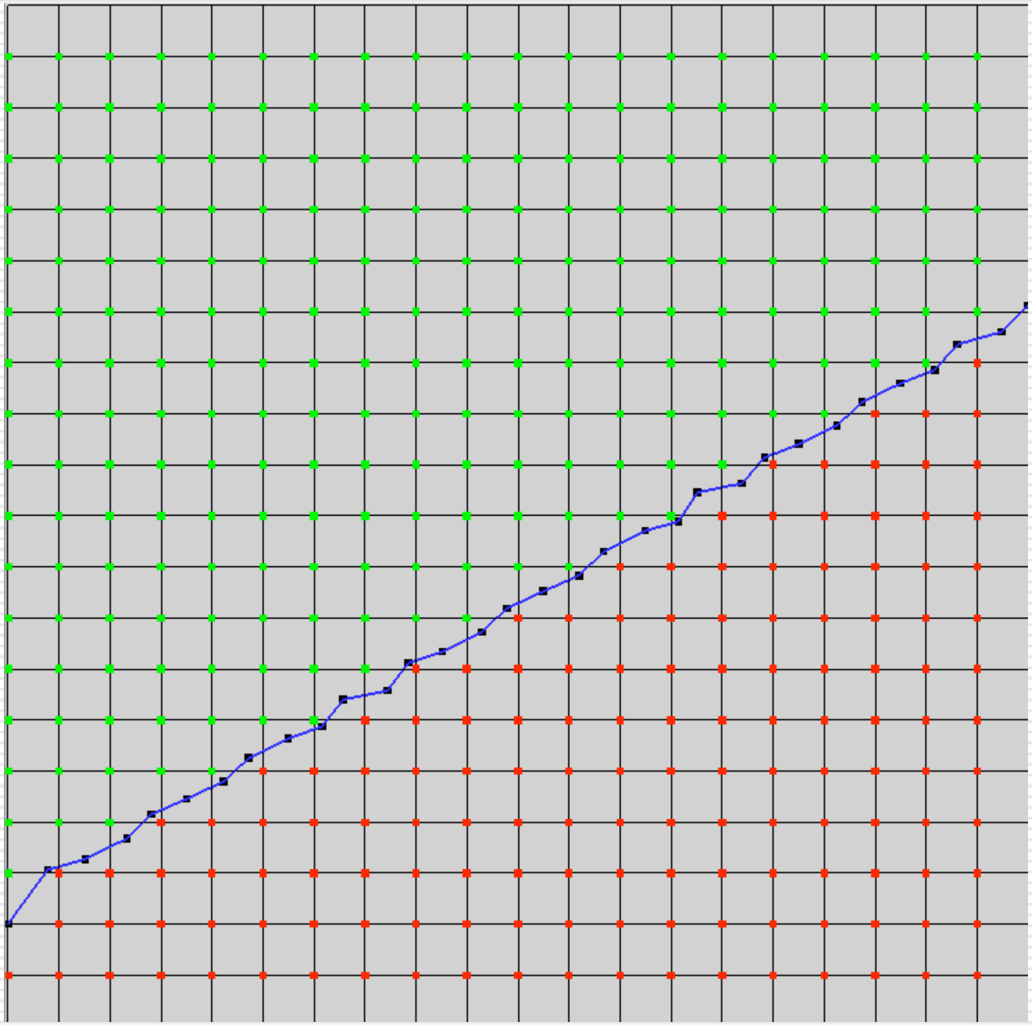

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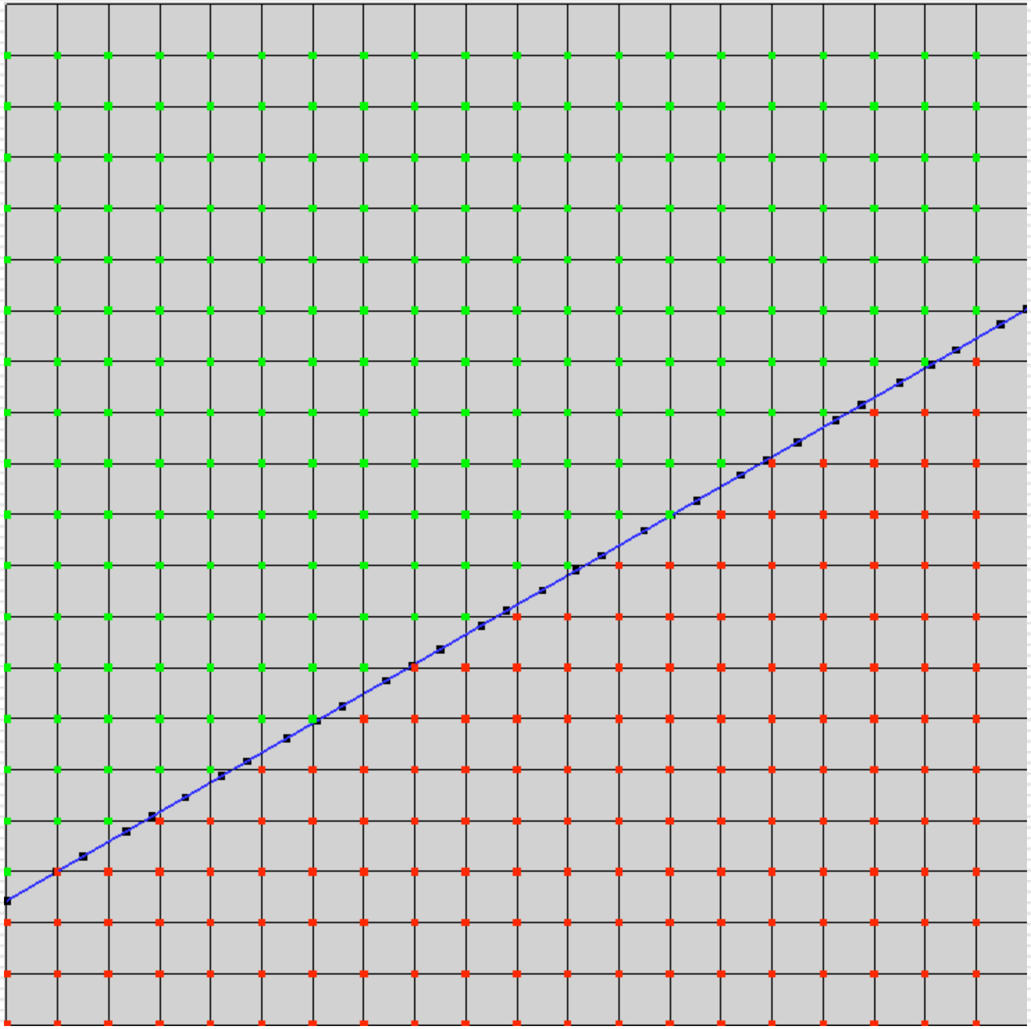
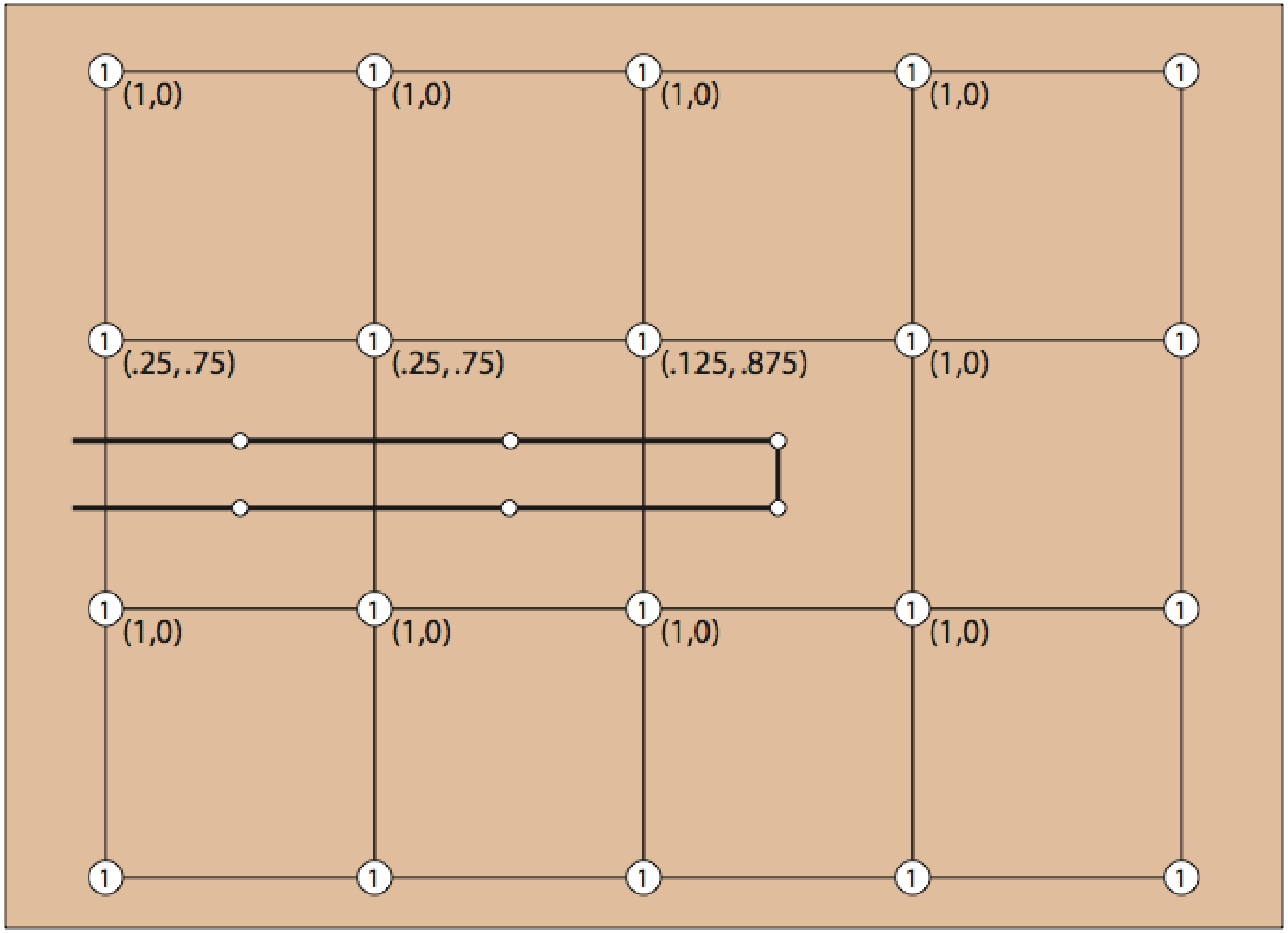


Problems -- fine detail



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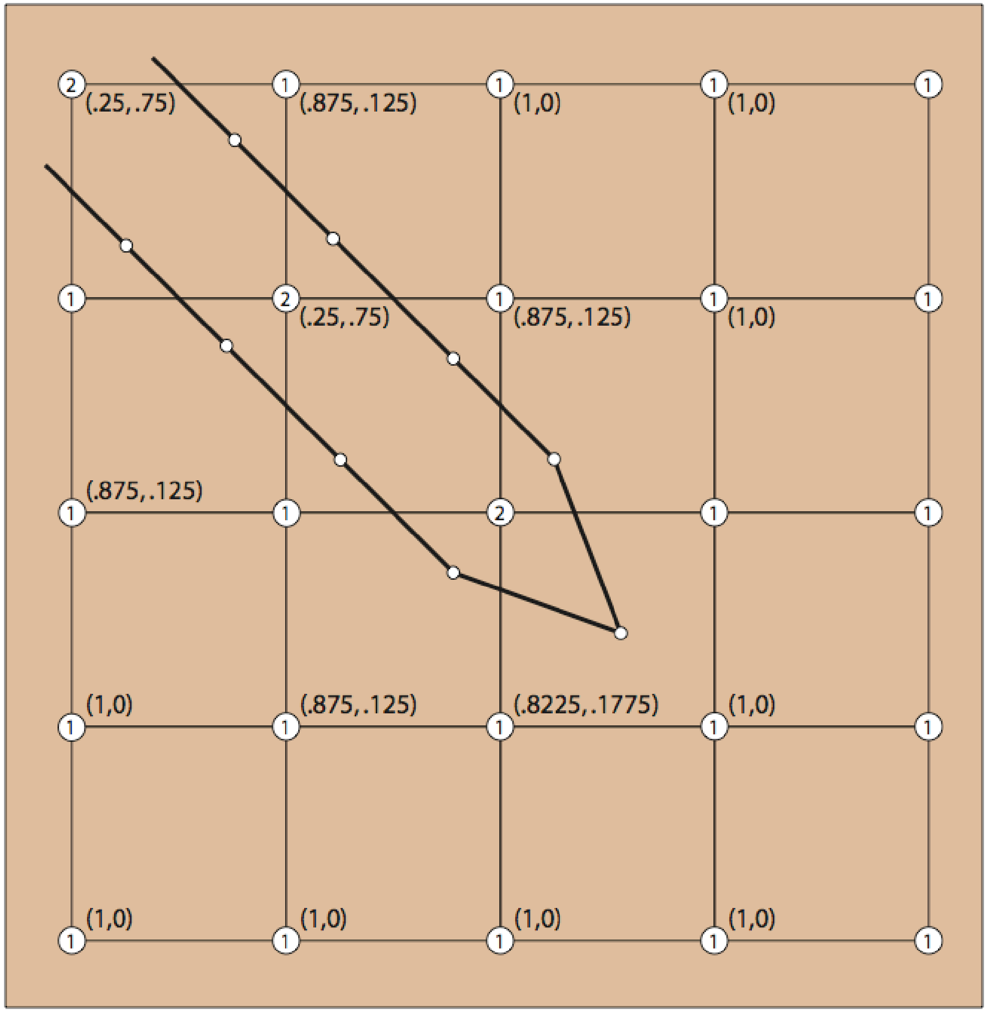

Needs

- An algorithm that “faithfully” reproduces material interfaces
  - The volume fractions induced by the generated material boundary should be the “same” as the original volume fractions
- The algorithm should scale with data set size
  - Currently equivalent to marching cubes
- The method should be fast!
- The method should detect “fine detail”.

Thank You

joy@cs.ucdavis.edu

http://graphics.cs.ucdavis.edu

http://graphics.cs.ucdavis.edu/~joy